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The following Questions, which were proposed in a late number of the Mechanics' Magazine, are, in consequence of some mistakes then made in them, again offered for consideration, with some modifications and additions.

QUESTIONS RESPECTING WATER-WHEELS, AND HEATING AND VENTILATING DWELLING HOUSES, OR OTHER BUILDINGS.

Can a stream of water be used to as much advantage, or made to do as much work, upon a horizontal wheel as upon a vertical one; and if so, what is the best construction for one, and what the cost of building it?

Can the same quantity of water that is let, in a thin sheet, upon a vertical wheel, (that is a wheel upon a horizontal shaft,) be made, in any way, to produce the same effect, when let in solid column upon a horizontal wheel, on a vertical shaft?

What have been the results of the experiments upon water wheels, made under the direction of the Franklin Institute, at Philadelphia? What kind of wheel was found best adapted to, or most effective under any given head and fall?

What is the best and most economical mode of heating dwelling-houses, schools, and lecture rooms, factories or other large buildings? By introducing heated air from a furnace—by pipes, heated by steam, carried around the sides of each room, or by similar pipes filled with boiling water?

What is the requisite size of a furnace to heat a room or a house of any given dimensions? What should be the size of the flue, for warm air, for heating the whole house; and what that of the branch flue for each particular room?

What is the best construction for the furnace-pipes, &c. upon the hot air, steam, or hot water plan; and what quantity of fuel (wood or coal) will be consumed per hour, if the fire be kept up, day and night, upon each plan, and what the cost?

What are the requisite dimensions of the furnace, boiler, pipes, &c. to be properly proportioned to the size of the whole building and to each room; and what the whole cost?

Are pipes of hot water, which are used to such advantage in England, sufficient for the purpose in a country where the winters are so intensely cold as ours sometimes are?

D*** F*****.

The following communication is in reply to some queries published in a late number, and now re-published in consequence of several errors in the first publication. The information it furnishes appears to be the result of the observations of a practical man.

We may here remark that some successful observations on heating by steam, are contained in a work, lately received by us, and from which we shall extract much interesting matter on this and other subjects, as soon as we can dispose of the matter already on our hands.

NEW MODES OF HEATING BUILDINGS.

Mr. MINOR:—In No. 38, p. 98, of the Magazine, your correspondent D*** F***** inquires what is the best and most economical mode of heating large buildings. As no one more able has replied to this inquiry, in the succeeding numbers, I venture to trouble you with a few casual observations made by me during a few years residence in London; and to request the publication of them, in case you think them likely to be of sufficient use to warrant their appearance in your valuable work.

All the methods I have seen may be divided into two classes,—those in which

water intervenes between the fire and the atmosphere,—and those in which the fire is uncovered, or separated from the atmosphere merely by plates of iron. To the second of these there is a well known objection, that the quality of the air is injured by contact with heated iron, in so great a degree as to cause headache and unpleasant sensations in the eyes and even in the skin generally. By some this is said to be owing to a change in the electric state of the air; by others, to the absorption of oxygen by the heated metal:—the remedy they both propose is, to evaporate water; but it has not been shown to my satisfaction, that this entirely removes the evil, or that it does not introduce a dampness that is not always desirable. Besides, this principal objection, there are frequently gases, dust, smoke, and unpleasant odors, arising from stoves and open fires, and particularly from those complicated and expensive rattle-traps, called air-furnaces. From my own observation, and from the verbal reports of many who have used them, and from all that I have read on the subject, it appears that the first class of contrivances are not liable to injure the air, as the others do, by giving it the power of causing headache, &c. by surcharging it with vapor, or dust, gases, or any thing else objectionable;—except that in the case of heating by steam, I have read a statement that it sometimes causes an unpleasant odor; owing, probably to the particular metal of which the pipes are made; for the complaint is not applied generally to this method.

So much for the *quality* of the heat obtained by these different methods:—I will now state what little I know of its cost. An obvious advantage of furnaces, stoves, etc., is, that if they are well constructed, you may burn in them almost any kind or quality of fuel, and thereby save the difference between the cheapest and dearest, (supposing, of course, that they are not in your parlors, or exposed to view.) Another advantage is, that you may dispense with the incumbrance of chimnies, and a great deal of expensive ornamental work, amounting, I am told, to a thousand dollars in many houses. But as to the comparative cheapness in respect to fuel of "hot air," "steam," and "hot water," I can only mention a fact reported in the London Journal of Arts and Sciences: that in one case, where hot water was introduced into a house that had previously been heated by hot air, the saving of fuel was one third; but this was not considered a fair test, as the air-furnace had not been well constructed.

At this moment, while I am writing, I have a smoke coming from an air-furnace flue in the corner of my room; by which I am prompted to censure the quackery of the unscientific persons who make these things in such a way that they get filled with dirt, and do not give you a chance to clean them, or remove the oxidised pipe, without pulling down a great quantity of brick-work. The one I have, though economical in respect to fuel, is a nuisance in all other respects, and was still worse before I made a better arrangement of the smoke-pipe, which the stupid constructor had run, after an ascent of two and a half feet, horizontally, for eighteen feet, to its insertion into the kitchen chimney, the large fire-place of which was open immediately under it. Though I consider it for the general good, and therefore for every man's particular interest, to be rather gentle in censuring the well intended blunders of half-ingenious, and wholly unlearned men, yet the number of these nuisances, so expensive at first, and so liable to get out of order, and so difficult to repair, is so rapidly increasing, that I feel bound to give my feeble evidence against all that I have ever seen of them. The fundamental principle on which they are made, is good; but in their construction all simplicity is eschewed, as if complication and multitude of parts were a proof of genius, and not strong presumptive evidence of the want of it. The only arrangement on this principle that I remember to have seen, that is free from the objections just enumerated, was a simple stove, (Dr. Nott's, I believe,) placed in a fire-proof closet about four feet square, with a door of sufficient size to admit a person, in the top of which were perforations, through which the heated air passed to the rooms above.

As to the original cost of hot water and steam apparatus, and the quantity of heating surface necessary in each, I am not able to say much. It is stated in the "Encyclopedia Americana" that one square foot of steam-pipe has been found sufficient to heat two hundred cubic feet of air; but this may have been for the English climate. In Perkins' hot water, called the "high pressure" apparatus, rolled iron pipes are used, hermetically sealed, so that the water is confined and heated to 350° or higher,—consequently much less pipe is required than in those where they are kept at 212°, or a very little over. In London these iron pipes are frequently used for gas, instead of lead, which answers the purpose quite well; so I presume their cost cannot much exceed that of lead pipe. One great advantage of this "high pressure" method is, that all your boiling may be done without the cost and dirt of an extra fire, and in wooden or any other vessels, simply by projecting the pipe from the wall a foot or so, bending it downwards, and making a coil, and returning it upwards and back to the wall. The high temperature of the water circulating within the pipe, will casue that in any vessel placed under it to boil rapidly. It is hardly necessary to state that the pipe, after running and coiling in the partitions of the rooms to be heated, returns into itself somewhat below the level of the fire; so that the water which has given off part of its heat, being denser than that which has but just passed through the fire, gravitates with greater power, and forces up the other, and thus keeps up a constant circulation. Your correspondent will find these various methods detailed at length, in those volumes of the London Mechanics' Magazine, and the London Journal of Arts and Sciences, published since 1827, which volumes he may get from Francis' Library, under Peale's Museum.

It may be well to mention that Mr. Perkins is an American, and perhaps has a patent right in this country. There are other modifications of the hot water principle invented by Englishmen, and therefore not patented here, and which the laws of honor will allow us to use freely, so long as the legal enactments restricting commerce in the products of genius and industry in the two countries are allowed to remain in force.

Your obt. servt.,
J. K. F.

New-York, June 4, 1836.

NOTE.—I had almost forgotten the queswhether the heat from water pipes is sufficient for the coldest weather in our winters? There will be no difficulty on that score if your pipe is long enough, and your fire hot enough. I have been told that Mr. Perkins says he can heat a whole parish from one fire.

MARBLE CEMENT.

An important improvement, which has been for several years in progress, is about being introduced to the more general notice of the public, and we believe into extensive use for building purposes. It is a composition or cement, of which the principal ingredient is marble or lime stone, which, when applied to the inner or outer walls of buildings, presents the appearance of polished marble, of the various hues and qualities which distinguish the beautiful material imitated. What would be thought of a magician who possessed the power of changing the sombre brick and stone walls of the buildings of a city, in one week, into substances resembling the most beautiful Grecian, Italian, Egyptian or Verd Antique Marble, or porphyry, like the rock of Gibraltar? Yet all this may be done by this invention of a humble citizen, of Orange county, in this State. This cement has been sufficiently tested by experiments on buildings, to satisfy practical men of its decided superiority over any other cement, stucco, or other hard finish for walls, hitherto known. In our next number we expect to be able to furnish the public with some interesting particulars, on this subject; and in the mean time we can state, that a company has been formed, in this city, to carry on the operations connected with the manufacture of this new cement, and its application to buildings. Those who are curious in these

matters, may obtain further information in relation to it, by applying at this office, or at the office of Edwin Williams, over Leavitt, Lord & Co., Broadway.

STEAM, *versus* WATER.

Few persons even in this age of inquiry and improvement seem to be aware of the vast superiority of steam over every other form of motive power. Many are still, by this assertion, reminded of the anecdote of the famous Brindley. In giving evidence before a Committee of the House of Commons on the subject of Canals, he spoke of their superiority as a mode of communication in such decided terms, that a member asked for what he thought rivers were intended? he unhesitatingly replied, "*to feed canals.*" Now, though we say that the manufacturer will one day "feed his boiler from the falls," we think that the assertion is not a bold one, and that it does admit of proof.

Some time ago, our attention was directed to a comparison of the expense of the two forms of power in the village of Lowell, possessed of the best water power in the Union. The expense of Steam to Water was said to be as 100 to 125.

We have since often had this subject in mind, in reference to the more improved use of steam, and particularly to the economy of the rotary engine of Avery.

Pursuing the comparison, we have collected some of the more prominent disadvantages of the usual hydraulic system, and the corresponding advantage of steam power.

The first item of cost is that of the water right, over and above the value of the ground as increased by any other advantages of locality. This expense is in no case trifling, and sometimes is positively enormous. There is of course no corresponding item of expenditure in the use of steam, an engine working as well on the top of a hill as in the bottom of a valley.

2d. The outlay upon wheels, dams, and other hydraulic works. This is often much greater than would be necessary for the average pressure, provided it were constant —that is, we are to erect works to support much more water than we have supplied through three quarters of the year. Freshets, &c. are to be provided against, at an increased cost. It is well known that in some locations the provision for such contingencies is no small portion of the whole capital employed.

It is this expense, other things being equal, that is to be compared with the cost of an engine, and the comparison is favorable to the latter.

3d. After every precaution, damages from floods are of constant occurrence, and their repair is exceedingly costly.

4th. The delay caused by freshets, &c., producing a stoppage from the too great supply of power.

5th. The delay in seasons of drought, when the supply is insufficient.

These last are most vexatious occurrences, preventing work often times when most is to be done, and the uncertainty arising from the possibility of such delays and accidents, is a constant care to the manager of such an establishment, whereas to the consumer of steam, the perfect certainty of the amount and regularity of the supply of power is a great auxiliary in conducting business.

For a steam engine, the only use of water is a sufficiency for the boiler; and in these days of economy of heat and steam, a very small quantity of fuel is used, and but little water. We have seen a rotary engine, estimated at 15 horse power, evaporating but 40 gallons per hour.

6th. Delay in winter, and in our uncertain climate this may sometimes be considerable, and in an establishment of great extent perhaps fatal.

To balance all these expenses, peculiar to the use of hydraulic power, there is, as far as we can recollect, but one peculiar to that of steam, namely, *fuel.* Now in saw mills this expense is nothing, and in all instances much less than formerly.

Our persevering countryman, Dr. Nott. has already succeeded in greatly reducing this item of cost—and he does not yet appear to be satisfied.

As regards fuel, Avery's Engine has im-

mense advantages over others, inasmuch as the quantity of water used is less than in any other case. The elasticity of the steam operates more advantageously than in any other construction, the small quantity of water used being a proof of this.

In the engine above referred to, the cost for coal was rather less than $1 for ten hours.

It is almost needless to observe that, in many large establishments, manufactories, &c., the application of a portion of the steam to heating, &c., nearly, if not quite, compensates the cost of fuel. The certainty and uniformity of this method of drying goods, have fully established its superiority. Indeed, in the art of dyeing, certain colors owe their brilliancy to the rapid and high heat of steam, and they could be produced in no other way. While speaking of this use of steam, we must notice an engine erected in the Astor Hotel. This is a small engine of 5 horse power; its use is to pump water from the different cisterns to all parts of the house—supply the baths with hot and cold water—clean knives—brush shoes—roast and grind coffee; and the steam cooks the various dishes in the kitchen, and also dries the clothes, which by this method of proceeding are ready for use with unprecedented despatch.

To these and numberless other uses is this engine turned, saving an immense number of servants, a great quantity of fuel, and a vast deal of time.

(The exhaust steam pipe of this engine is over 300 feet long.)

One of the greatest advantages of steam power, in many cases, is, that it admits of change of locality, without injury to the machinery, and often with benefit to the employer.

In this respect again Avery's Engine stands pre-eminent. The machinery is beautifully compact, and consequently portable. An engine of 15 horse power is hardly a load for a horse, the whole weighing less than 600 pounds.

Let us suppose, that a man purchases a piece of timber land, of prime quality, but unfortunately (as is thought) away from any water course.

Let him procure an Avery's Engine; and this, connected with his saw mill, can be placed upon wheels and moved, by the engine itself, if he pleases, to any part of his land. (Mills capable of such an arrangement, and very compact, are now easily to to be procured.)

Let him locate his mill near a spring, and commence operations. The waste and rubbish, that in most cases is a drug, is entirely consumed by the engine; the grouud is cleared, and nothing is to be removed but the perfectly formed timber.

Among other useful applications of such an engine, in the forest itself, no one can be equal in beauty of operation to the valuable *stave machine* of Philip Cornell, N. Y. (A drawing and description of this machine will be found upon the next page.) This machine promises to be of great service. With such an arrangement as that of the saw mill above mentioned, nearly if not quite double the usual number of staves can be cut from the timber before transportation, and these are already dressed and ready for use, either for liquids or solids.

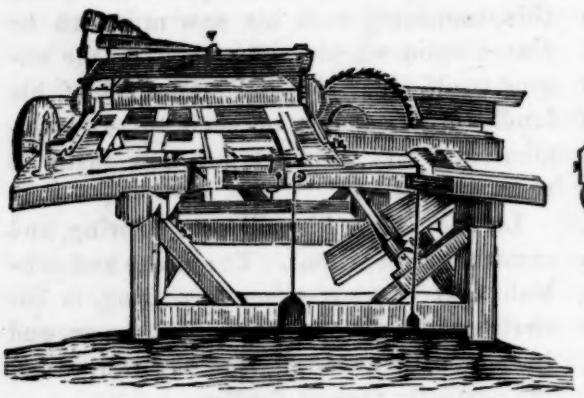
These are only a few of the very many useful applications of this sort of traveling machines. Others will suggest themselves to our readers.

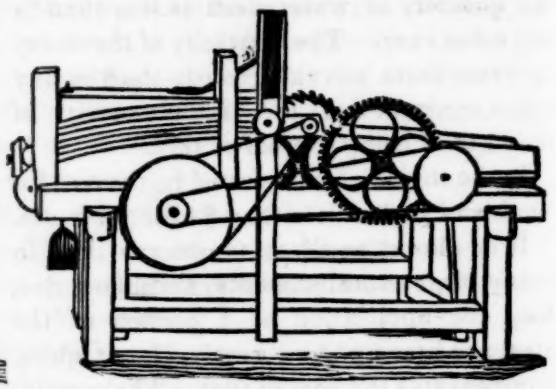
It must be very evident that, whatever brings into use property of little or no value, enabling the produce of such land to compete successfully with that of much better, must add to the wealth of the landholder, or timber merchant, a sum equal to the cost of the best land.

Thus a greater uniformity of value would result, and of consequence a more equal competency to those on or away from great water courses and canals.

Our object is to draw attention to this question, and we should be much gratified if any of our friends would furnish us with such information on the subject as they may have at their command.

This information from various quarters, when collected, might furnish results equally useful and interesting—and we shall feel most happy in becoming the medium of their communication to the public.





CORNELL'S PATENT STAVE MACHINE.

Numerous inventions have at various times been patented to facilitate the making of staves for casks, barrels, &c., but few of which have proved successful. The one which is the subject of the present notice forms an exception. Competent judges give it a decided preference over any similar invention and are of opinion that it must eventually supersede the present economy of the branch of coopering which prepares the staves for the casks. This machine was invented by Philip Cornell a native of Vermont, but for many years a resident of Cayuga County, in this State, who died in 1834, soon after his invention was introduced to the notice of the public. At the last Fair of the American Institute this Machine was exhibited in operation and attracted great attention, and a gold medal was awarded as a premium to the proprietors by the Institute. The patent is now owned by a company in this city, who we understand offer for sale rights for making and using the machine on liberal terms. [Mr. Edwin Williams of this city, is Agent for the proprietors, office No. 180 Broadway.]

This machine is now in operation in several parts of the United States, and fully answers the expectations of the inventor and those who have purchased a right to use it. Like other labour saving machines which have been introduced into the mechanic arts, it has encountered the prejudices of many who are interested in the branch of industry to which it is applied, no doubt under the apprehension that it would lessen the demand for their labor. Experience will prove in this, as it has in other instances, that the apprehension is not well founded; that instead of lessening the demand for workmen, it will be increased, by the increased demand for the articles of which it produces but a part, requiring the hand of the workman to complete.

The sawing machine and the dresser, which together constitute a complete machine, will occupy a space of about ten feet square, and can be attached to an ordinary saw mill at an expense of geering not to exceed $50, and in most cases for a less sum. The power required to operate one machine, either steam, water, or wind, is equal to about seven horses. Two men will be required to a machine. An ordinary mill, with one saw, will supply timber for three machines. The timber is first sawed into plank $3\frac{3}{4}$ inches thick, and then cut to the length of the staves required.—Staves can be made from any kind of wood without regard to the grain. A machine will complete two thousand oak barrel staves per day, of ten working hours; these staves require assorting, and such as are unfit for tight casks, answer well for dry ones. The loss of stuff is very trifling. The cost of a machine for hogshead or pipe staves is $325, and for barrel staves $300, exclusive of the charge for patent right.

Extract from the Report of the Committee of the American Institute, adopted October 1, 1835.

"With dilligent attention and adequate power, one set of these machines, of which there are in effect three, two of them, the bevelling and smoothing machines being separate in their action, although constructed in one frame, and the machine for sawing out the staves being separate in another, it is highly probable that two men supplied with material at hand, could saw, bevel, and smooth *three thousand* barrel staves in a day of ten working hours.

"These machines are evidently great labor saving machines, and it is believed they are more perfect than any others designed for this manufacture. They possess the rare test of mechanical perfection, in being quite independent of great skill or cleverness in the operator. Any faithful, diligent, and in-

dustrious labourer, of ordinary intelligence, can work them with advantage.

"Your Committee recommend these machines as eminitely useful in the manufacture of staves, and anticipate that their perfection will suggest some corresponding improvement in the manufacture of barrel and pipe heads, yet much needed in this branch of the arts."

Copy of a letter from A. W. EDWARDS, *of Fulton, Oswego County, New-York, who had in use two of the Machines, and was waiting for the other.*

"I am in very great want of a dressing Machine. I have 30,000 staves already seasoned to dress, and plenty of contracts waiting to be supplied. I would not be without the Machine for ten dollars per day. I find no difficulty in cutting *ten staves* per minute, and I can very nearly average that from Oak timber, of which I use considerable.

From BROWN, LORD & Co. *of Bangor, Maine, who have had a Machine in operation one year.*

"In answer to your request respecting Philip Cornell's Stave Machine, we are happy to state, that it fully answers our expectations, and all concur in giving it their decided approbation after seeing it. As it respects the market for the staves, we have no difficulty in disposing of all the staves that we make, at about twice the market price of similar staves made in the usual way. BROWN, LORD & Co."

From the Washington (North Carolina) Whig, February 27, 1836.

"*Cornell's Stave Machine*,—The staves made by this Machine are, without exception the most beautiful and correctly jointed and dressed staves we ever beheld. A barrel made of Pine staves was exhibited full of *spirits of turpentine*, which had been filled about a week and remained perfectly tight. We were present when the same barrel had been filled with water before, and it was then perfectly tight also. There does not remain a doubt but that it (the machine) makes staves from any kind of wood, far superior to those dressed in the usual way. Barrels made of them need no flagging, and the staves must make a tight joint. The bilge or size of the barrel may be varied at pleasure, as well as the thickness or length of the stave."

Extract of a letter from Messrs TANNAHILL & LAVENDER, *Washington, N. C., May* 25, 1836.

"The sample of staves (made by Cornell's Machine,) sent by us to the West Indies, were very much approved, and contracts might have been made for cargoes."

From JOHN P. OBER & Co. *Elsworth, Maine.*

The subscribers have had in operation for three months, at Elsworth, Hancock County, Maine, one of Cornell's Patent Stave Machines, and find it to answer our expectations in every respect; we have finished twenty-eight staves, thirty-two inches long, of beach wood, in five minutes, and can average two thousand every day of ten working hours. We obtain for the staves for barrels of Beach, Birch and Ash, from twelve to fifteen dollars per thousand, (nett 1,000.) We have proved the barrels and casks made with the Machine, and find they will answer for liquor or dry casks, as well as those made from any other staves.

JOHN P. OBER & Co.

(One of this firm is a Practical Cooper.)

Those who wish to see the Machine in operation in this city may have an opportunity by calling at the office of the Mechanics Magazine and Railroad Journal, 132 Nassau street.

From the immense mass of testimony, collected by the Select Committee of the House of Commons on Accidents in Mines, we have selected the following article in relation to a novel and ingenious method of lighting, not only mines, but all places where actual exposure of flame to the atmosphere, might be productive of dangerous explosions or conflagrations.

We recollect a domestic application of this method, that was ingenious enough in its operation.

A gentleman had lost a knife of some value, at the bottom of a very deep well. By means of a large mirror, he reflected the sun's rays to the bottom of the well, and immediately discovered the position of the knife. A magnet, attached to a line, was let down upon it, and brought up the knife with it. We have not unfrequently used this method of illumination, when in search of some small article in an obscure corner of a dark closet.

MR. GOLDSWORTHY GURNEY'S SAFETY METHOD OF LIGHTING MINES.

(From the Minutes of Evidence taken before the Select Committee of the House of Commons on Accidents in Mines.)

Has it ever occurred to you to consider

whether mines might be lit under such circumstances as to do away with the necessity of the moveable lamp?—The subject has been one which I have lately considered a good deal, in conseqence of being engaged again in experiments of a similar kind to those of 1822; I have recently made a series of experiments for the Trinity House on artificial light; and the results of these experiments, and observations connected with them, induce me to believe it possible to light coal mines without taking flame at all into mines: In a few words, I will state, that I think it capable of being done by reflected light. In these experiments I found artificial light may be produced, so intense that when placed in the focus of a parabolical reflector, it will throw a distinct shadow at the distance of eleven miles. Now, as light is capable of being concentrated, reflected, and refracted in any angles, or in any direction, or in any quantities, I think it possible that such light may be reflected into mines, subdivided, and passed through the galleries, in sufficient quantities and intensity as to enable miners to work far better than by lamps of any description. The light itself, and the combustion to produce it, could be placed above the shaft, in the open air. If, however, from mechanical difficulties, such as obstructing parts in the way of its passage down the shaft, it is possible that the light might be placed in some safe part of the mine itself, where fire-damp is never found, and from thence be reflected and refracted through the various parts of the mine. I have made experiments with this view, and have found light capable of being reflected, in various directions, with simple and inexpensive reflectors; the first reflection requires a true parabolic reflector, but afterwards plain and simple surfaces will do. Possibly, the whole mine and galleries may be all lit by a single light, if not very extensive; but if seven lights of the first order be placed in the focus of seven true 12 inch parabolas, and arranged within a circle of 3 feet diameter, which they may be, I firmly believe one of the longest mines might be most effectually lighted in every gallery. No one can judge of the power and management of this light who has not seen it, or possibly conceive its practicability to the subject before us. I need not go into explanation of the manner of doing it. The Committee will remember that, as the angle of reflection is always equal to the angle of incidence, we may throw the light in whatever direction we please; by this means we may turn it round a corner at right angles, or in any angles suited to the drifts the mine happens to be cut into. The practical difficulties connected with this plan chiefly, I conceive, are those arising from obstructions in the galleries: one, for instance, is the air-doors, which are necessarily used for ventilation; there is no difficulty, however, in such case in placing a piece of plate-glass in some particular part of the door, so as to admit the passage of the light through it, or a second light may be brought in an opposite direction; again, if the galleries are so low that there is not room for the light, coal wagons or miners, to pass together, it is possible so to widen them, or enlarge them, that there would be a sufficient space for a sufficient quantity of light to pass; it may be passed through very small openings by strong concentration, and afterwards diverged as may be necessary.

Would it not be attended with great expense?—No.

Less than the ordinary mode?—I am not prepared to say exactly, but I think it would not be more expensive than the present mode. In case the light is not required to be very great, I think a light of less intensity might be used, with advantage, that would be less expensive than the present oil-lamps. A very simple but powerful light, is about to be adopted by the Trinity Board for light-houses, which, by way of distinction, and in reference to the place where it was discovered, has been called the "Bude Light." This light produces an intensity 140 times that of the present Argand burner; this light, therefore, may be used where the ramifications of the mine, or greater extent, does not require the first order, namely, the lime light. In some cases, the light from the common Argand burner, placed in a parabolic reflector, may be sufficient, and in that case it certainly would be cheaper. I am of opinion, from the experiments and investigations made at the Trinity House, that the light from lime, and also the Bude Light, is less expensive than that of the ordinary light, taking quantity and intensity into account, which may be sub-divided to equal intensity with the first; the intensity of the one is 290 times greater than the other, and the intensity of the second 140; thus one is capable of giving the same quantity as 290 Argand burners, and the other as much as 140.

The term Bude Light has no application to the peculiar manner in which it is produced?—It is a term simply used to distinguish it.

From what is it derived?—It is produced by striking nacent carbon, evolved in the combustion of oil, resin, or similar bodies, with oxygen gas.

You have spoken of difficulties in the introduction of this new system of lighting

in the mines of this country; apply your mind for a moment to the difficulties which might arise in the mines not having above two or three feet depth of seam?—I think such difficulties are to be overcome by inexpensive boring or widening to admit the light to pass; in such a drift a stream of light, highly concentrated, of six inches diameter, would be ample, and whether it passed by the side or the top of the gallery, it matters not. A large quantity of light, by simple means, might be concentrated in such case, and passed along such an opening, and afterwards diverged in larger galleries, if such was indispensable. These are points upon which I think the Committee will find other persons more capable of giving information on than myself.

Supposing a light is required to be in a straight line for a mile, there would be no difficulty in obtaining a sufficient light at the terminus?—The light at the distance of a mile would enable you to read the smallest print. If it is reflected two or three times in that distance through a circuitous passage, you would lose very little, if you use good reflectors made of speculam metal. The quantity of light lost by such reflection is very trifling.

The question related to the casting of light upon one object at the distance named?—So I have answered it; it is of little consequence whether it be straight a-head, or at the end of a curved or angular gallery.

In case that light is then to be divided into fifty different directions, so as to suit different galleries, what would be the consequence as regards the terminus?—The result would be, that the light would simply be reduced fifty times in quantity; it would be divided into fifty portions; it would then be still stronger than the strongest Argand burners; and I beg to be understood as meaning the Argand burner used on the tables of private families, not the little oil burner of the safety-lamp. I will make an observation here which may be important, namely, the stream of light may be sent through the various galleries, and when it arrives at the situation where the men are working, every man, with a little reflector or refractor, as may be determined on, may take that portion of light which may be intended for him, and no more, from the great stream, and thus limit him the quantity of light that he may abstract from the stream; which portion he may at pleasure direct wherever he pleases on the work before him; so that instead of a lamp, he would work with a little diverging reflector, or refractor, which he would carry in his pocket, perhaps of the size of half-a-crown.

Do you not think that the experiments of scientific men might be better made in the mines themselves, than they could be in their own laboratory?—Certainly; if a principle is established, it rests as a matter of mechanical detail, or of mechanical situation and position, to know whether it can or cannot be applied, practically, with advantage. Sir George Cayley informs me that he used the principle of reflection to throw daylight to some men who were working a deep well. It had a beautiful effect, and answered the purpose perfectly. His reflector was nothing more than a piece of tin plate. The daylight is not sufficiently intense; we cannot focus it so as to be passed through the galleries of mines.

In your opinion, would the experiment be better conducted by placing the light above the shaft, or at the bottom of the shaft?—It would depend on the depth and size of the shaft.

Assume 200 yards in depth?—In such case above; you get at the materials and apparatus for forming the light better; the distance of 200 yards has very little effect in diminishing the light; reflected light does not obey the same laws as radiated light; radiated light diminishes as the squares of the distances, but reflected light does not; this is contrary to received opinions, but I am satisfied it is corect, from the observations I have lately made.

You have not supposed any difficulties in the application of this light, beyond those already stated, which the Committee understand to be the interruptions occasioned by stoppings or trap-doors in the mines, or the extreme sub-division of the reflected light?—I have: there are others, but I think of minor importance, which can only be justly appreciated in practice.

The shafts of the mines are placed at right angles, that is, they are driven along, and they begin at the further end, and then work upwards; is there any difficulty in transmitting the light at right angles?—Not any difficulty whatever; you may transmit the light in any angle you please; it may first be thrown down a shaft, and then sent into any angle, upwards or downwards, or on one side or on another.

Suppose there be a space of two or three feet left on one side, or both sides, of the carriages conveying the minerals along the galleries, the light might be transmitted independently of the space occupied by the carriages?—Certainly.

Or through a similar space above the carriages?—Yes.

And you propose, to obviate the difficulty of passing through the trap-doors, that means in the mines, by the insertion of glass in those doors; what is the smallest

size you would consider sufficient for that purpose?—It would depend upon the situation in which the door was placed in the mine; if in the first gallery, where you wanted the full stream or supply of light to pass, you would require twenty inches diameter; when doors occur further on, in the division of light, perhaps three or four inches in diameter would be sufficient.

Would that be sufficient to light a gallery at the distance beyond the door many hundred yards, if twelve feet wide?—Certainly. There is another valuable natural fact that I would mention here: the stream of light, as it passes through the air, is refracted by the atmosphere, and thrown in all directions several yards, with an intensity sufficient for practical purposes. My house at Bude has a long gallery in it; I passed a stream of reflected light through that gallery; every bed-room entering into the gallery was sufficiently illuminated in every part for a person to pick up a pin. The light in the bed-rooms was refracted light, from the reflected light passing through the gallery. I conceive that unless men are working at some distance from the stream of light through a gallery, a reflector would be scarcely necessary for them. Dust, floating in the atmosphere, reflects a good deal of light sideways.

Would the accumulation of dust upon glass so inserted in one of the trap-doors, be a serious impediment to the light?—Not practically, because it could be easily wiped away.

Are you aware that a boy is generally stationed to take charge of those doors?—Yes.

And of course, he might have instructions to keep the glass perfectly clean?—Certainly.

THE SELECT COMMITTEE APPOINTED TO TAKE INTO CONSIDERATION THE STATE AND CONDITION OF THE PATENT OFFICE, AND THE LAWS RELATING TO THE ISSUING OF PATENTS FOR NEW AND USEFUL INVENTIONS AND DISCOVERIES, SUBMIT THE FOLLOWING REPORT:

(Continued from page 319.)

mechanism or manufacture has, for the last twenty years, been brought across the Atlantic, that has not, on being returned, borne the distinguished marks of the superior ingenuity of American mechanists? Formerly, we borrowed and copied much that was valuable from Europe. Now, Europe is borrowing and copying, with no little advantage, from us; and she must not be too much surprised if she shall soon find a formidable balance against her.

To carry fully into effect the objects which have been had in view, it will be necessary to provide larger and more commodious rooms for models, &c., than those now occupied for that purpose.—They are insufficient for the models of machinery and other inventions now deposited there, and the number will be increasing several hundred, perhaps a thousand, every year. A great number, supposed to be about five hundred, from a want of room for them elsewhere, have been stowed away in a dark garret.—Those which occupy the rooms designed for them, are crowded together in a manner unfavorable for exhibition or examination. In such a situation, it is impossible to give them any systematic or scientific arrangement. This disorder and confusion must necessarily be increased by the addition of those hereafter furnished, or they must be consigned to the garret, the common receptacle, where, instead of promoting a taste for, and facilitating the study of, the useful arts, they will only afford evidence of the improvidence of the Government. In addition to this, the present building is too much exposed to destruction by fire. The loss of records and drawings and of the several thousands of interesting and valuable models now preserved there, would be, in a great degree, irreparable. There is no additional room to be had in the building they now occupy. The Post Office Department, in the same building, instead of having any room to spare which is now appropriated to it, requires a considerable extension of accommodations, from its increased and increasing business. It needs the whole building. The only way, therefore, of providing the necessary extension of room for the accommodation of the Post Office Department, and the city post office, and of providing the requisite accommodation for the Patent Office, is to erect a suitable fire-proof building for the latter on some one of the public lots. There are ample funds arising from duties on patents, heretofore paid into the Treasury, to the account of clerk hire in that office, which remain un-

expended. A portion of that surplus fund, being now about $152,000, may well be appropriated to the construction of a building which should be commodious and comparatively safe from fire.

Such a building as this branch of the public interests requires, would do honor to the Government and the country. The Patent Office, with such accommodations, containing the records of this age of inventions, displaying in its halls and galleries numberless models of igenious and useful mechanism, and contrivances in almost infinite variety, adapted to the mechanic arts, to manufactures, to husbandry, to navigation, steam power, horse power, water power, Railroad transportation, and, in fine, to all the common trades and mechanical pursuits of life, as well as to our rapidly multiplying and magnificent public works, would present an object of interest, and tend not a little to elevate our national character. It has been justly remarked that we can go into no mechanic shop, into no manufactory of any description, upon no farm or plantation, or travel a mile on our Railroads or in our steamboats, without seeing the evidence of our originality, and witnessing the fruits and effects of our ingenuity and enterprise. All the inventions and improvements in mechanism which have done so much towards advancing the useful arts and manufactures, should, as far as practicable, be exhibited in one view in the halls of the Patent Office.—Such a display would attract the attention of the many thousands who annually visit the capital of the Union from all quarters of the country, and all parts of the world. No other nation has yet any thing to be compared with it; neither England nor France has ever required models to be deposited of patented machinery. Collection of models and drawings have sometimes been made by private associations, but they are small in number compared with those we possess.

In addition to the models of machinery, it is proposed to embrace an exhibition of specimens of useful and elegant fabrics and of works of art, which manufacturers and artificers may place there for that purpose. It might, too, embrace a cabinet of interesting minerals, which may be received from time to time from the various parts of our widely-extended country, with polished specimens of its beautiful marbles from their different locations, illustrating the geology and many of the natural resources of the country; and, also, a collection of Indian curiosities and antiquities, many of which are now in the possession of one of the Departments, boxed up for want of some suitable place for their exhibition.

In short, the halls of the Patent Office should present a national museum of the arts, and be a general repository of all the inventions and improvements in machinery and manufactures, of which our country can claim the honor; together with such other objects of interest as might conveniently and properly be placed under the superintendence of the Commissioner. Such an institution, while it would be an object of just pride to every American, would have scarcely less influence in advancing and accelerating the progress of the useful arts and the improvement of our manufactures, than would even the encouragement afforded by granting patents for inventions or establishing high tariffs of protection.

With these views, the committee cannot hesitate to recommend an entire reorganization of the Patent Office, and several material alterations in our law of patents, suiting it to the present condition of the arts and the altered circumstances of the country.

A bill in conformity with our views is herewith submitted.

A BILL TO PROMOTE THE PROGRESS OF THE USEFUL ARTS, AND TO REPEAL ALL ACTS AND PARTS OF ACTS HERETOFORE MADE FOR THAT PURPOSE.

Be *it enacted by the Senate and House of Representatives of the United States of America, in Congress assembled*, That there shall be established, and attached to the department of State, an office to be denominated the Patent Office; the chief officer of which shall be called the Commissioner of Patents, to be appointed by the President, by and with the advice and consent of the Senate, whose duty it shall be under the direction of the head of the department, to superintend, execute, and perform, all such acts and things touching and respecting the granting and issuing of patents for

new and useful discoveries, inventions, and improvements as are herein provided for, or shall hereafter be, by law, directed to be done and performed, and shall have the charge and custody of all the books, records, papers, models, machines, and all other things belonging to said office. And said Commissioner shall receive the same compensation as is allowed by law to the Commisioner of the Indian Department.

SEC. 2. *And be it further enacted*, That there shall be, in said office, an inferior officer, to be appointed by the said principal officer, with the approval of the Secretary of State, and to be called the Chief Clerk of the Patent Office; who, in all cases during the necessary absence of the Commissioner, or when the said principal office shall become vacant, shall have the charge and custody of the seal, and of the records, books, papers, machines, models, and all other things belonging to the said office. And the said Commissioner may also, with like approval, appoint two other clerks, an examiner of patents, a draughtsman, a mechanist, and a messenger. The said chief clerk shall receive the annual salary of seventeen hundred dollars; two other clerks, twelve hundred and fifty dollars each; examiner, fifteen hundred dollars; draughtsman, twelve mechanist, one thousand dollars; and the messenger five hundred dollars.

SEC. 3. *And be it farther enacted*, That the said principal officer, and every other person to be appointed in the said office, shall, before he enters upon the duties of his office, or appointment, make oath or affirmation truly and faithfully to execute the trust committed to him. And the said Commisioner, and the chief clerk shall also, before entering upon their duties, severally give bonds with sureties, to the Treasurer of the United States, each in the sum of ——— dollars, with condition to render a true and faithful account to him, or his successor in office, quarterly, of all moneys which shall be by them respectively received for duties on patents, and for copies of records and drawings, and all other moneys received by virtue of such office.

SEC. 4. *And be it further enacted*, That the said Commissioner shall cause a seal of office to be made and provided for the said office, with such device as the President of the United States shall approve; and copies of any records, books, papers, or drawings, belonging to said office, under the signature of the said Commissioner, or when the office shall be vacant, under the signature of the chief clerk, with the said seal affixed, shall be competent evidence in all cases in wh ch the original records, books, papers, or drawings, would be evidence. And any person making application therefor, may have certified copies of the records, drawings, and other papers deposited in said office, on paying, for the written copies, the sum of ten cents for every page of one hundred words; and for copies of drawings, the reasonable expense of making the same.

SEC. 5. *And be it further enacted*, That all patents issuing from said office, shall be issued in the name of the United States, and under the seal of said office, and be signed by the Secretary of State, and countersigned by the Commissioner of said office, and shall be recorded, together with the descriptions, specification, and drawings, in the said office, in books to be kept for that purpose. Every such patent shall contain a short description of the invention or discovery, and in its terms grant to the applicant or applicants, his or their heirs, administrators, executors, or assigns, for a term not exceeding fourteen years, the full and exclusive right and liberty of using, and vending to others to be used, the said invention or dicsovery, referring to the specifications for particulars thereof, a copy of which shall be annexed to the patent, specifying what the patentee claims as his invention or discovery.

SEC. 6. *And be it further enacted*, That any person or persons having discovered or invented any new and useful art, machine, manufacture, or composition of matter, or any new and useful improvement on any art, machine, manufacture, or composition of matter, not known or used by others before his or their discovery or invention thereof, and not, at the time of his application for a patent, in public use or on sale, with his consent or allowance as the inventor or discoverer; and shall desire to obtain an exclusive property therein, may make application in writing to the Commissioner of Patents, expressing such desire, and the Commissioner, on due proceedings had, may grant a patent therefor. But before any inventor shall receive a patent for any such new invention or discovery, he shall deliver a writen description of his invention or

discovery, and of the manner and process of making, constructing, using, and compounding the same, in such full, clear, and exact terms, avoiding unnecessary prolixity, as to enable any person skilled in the art or science to which it appertains, or with which it is most nearly connected, to make, construct, compound, and use the same; and in case of any machine, he shall fully explain the priciple, and the several modes in which he has contemplated the application of that principle, or character by which it may be distinguished from other inventions; and shall particularly specify and point out the part, improvement, or combination, which he claims as his own invention or discovery. He shall, furthermore, accompany the whole with a drawing, or drawings, and written references, where the nature of the case admits of drawings, or with specimens of ingredients, and of the composition of matter, sufficient in quantity for the purpose of experiment, where the invention or discovery is of a composition of matter; which descriptions and drawings, signed by the inventor, and tested by 2 witnesses shall be filed in the patent office; and he shall, moreover, furnish a model of his machine, in all cases which admit of a representation by model, of a convenient size to exhibit advantageously its several parts. The applicant shall also make oath or affirmation that he does verily believe that he is the original inventor or discoverer of the art, machine, composition, or improvement, for which he solicits a patent, and that he does not know or believe that the same was ever before known or used; which oath or affirmation may be made before any person authorized by law to administer oaths.

SEC. 7. *And be it further enacted*, That, on the filing of any such application, description, and specification, and the payment of the duty hereinafter provided, the Commissioner shall make, or cause to be made, an examination of the alleged new invention or discovery; and if, on any such examination, it shall not appear to the Commissioner that the same had been known and used prior to such alledged discovery thereof by the applicant, or had been in public use, or on sale, with his consent or allowance prior to the application, if he shall deem it to be sufficiently useful and important, it shall be his duty to issue a patent therefor. But whenever, on such examation, it shall appear to the Commissioner that the applicant was not the original inventor or discoverer thereof, or that any part of that which is cclaimed as new had before been known and used as aforesaid, or that the description is defective and insufficient, he shall notify the applicant thereof, giving him, briefly, such information as may be useful in judging of the propriety of renewing his application, or of altering his specification to embrace only that part of the invention or discovery which is new. In every such case, if the applicant shall elect to withdraw his application, he shall be entitled to receive back—— dollars, part of the duty required by this act, on filing a notice in writing of such election in the Patent Office, a copy of which, certified by the Commissoner, shall be a sufficient warrant to the Treasurer for paying back to the applicant the said sum of ——— dollars. But if the applicant in such case shall persist in his claim for a patent, with or without any alteration of his specification, he shall be required to make oath or affirmation anew, in manner as aforesaid. And if the specification and claim shall not have been so modified as, in the opinion of the Commissioner, shall entitle the applicant to a patent, he may, on appeal, and upon request in writing, have the decision of a board of examiners, to be composed of three disinterested persons, who shall be appointed for that purpose by the Secretary of State, and to be selected for their knowledge and skill in the particular art, manufacture, or branch of science to which the alleged invention appertains; who shall be furnished with a certificate in wri ing, of the opinion and decision of the Commissioner, stating the particular grounds of his objection, and the part or parts of the invention which he considers as not entitled to be patented. And the said board shall give reasonable notice to the applicant, as well as to the Commissioner, of the time and place of their meeting, they may have an opportunity of furnishing them with such facts and evidence as they may deem necessary to a just decision; and it shall be the duty of the Commissioner to furnish the board of examiners with such information as he may possess relative to the matter under their consideration. And on an examination and consideration of the matter by such board, it shall be in their power, or of a majority of them, to reverse the decision of the Com-

missioner, either in whole or in part; and their opinion being certified to the Commissioner, he shall be governed thereby, in the further proceedings to be had on such application; *Provided, however*, That before a board shall be instituted in any such case, the applicant shall pay to the Commissioner the sum of ——— dollars, which shall be in full compensation to the persons who may be so appointed, for their examination and certificate as aforesaid.

SEC. 8. *And be it further enacted*, That whenever an application shall be made for a patent, which, in the opinion of the Commissioner, would interfere with any other patent for which an application may be pending, or with any unexpired patent which shall have been granted, it shall be the duty of the Commissioner to give notice thereof to such applicants, or patentees, as the case may be; and if either shall be dissatisfied with the decision of the Commissioner on the question of priority or right of invention, he may appeal from such decision, on the like terms and conditions as are provided in the preceding section of this act: and the like proceedings shall be had to determine which, or whether either of the applicants is entitled to receive a patent as prayed for.

SEC. 9. *And be it further enacted*, That before any application for a patent shall be considered by the Commissioner as aforesaid, the applicant shall pay into the Treasury of the United States, or into the Patent Office, or into any of the deposite banks, to the credit of the Treasury, if he be a citizen of the United States, or an alien and shall have been resident in the United States for one year next preceding, and shall have made oath of his intention to become a citizen thereof, the sum of forty dollars; if a subject of the King of Great Britain, the sum of five hundred dollars; and all other persons the sum of three hundred dollars; for which payment duplicate receipts shall be taken, one of which to be filed in the office of the Treasurer. And the moneys received into the Treasury under this act shall constitute a fund for the payment of the salaries of the officers and clerks, herein provided for, and all other expenses of the Patent Office, and to be called the patent fund.

SEC. 10. *And be it further enacted*, That where any person hath made, or shall have made, any new invention, discovery, or improvement, on account of which a patent might by virtue of this act be granted, and such person shall die before any patent shall be granted therefor, the right of applying for and obtaining such patent shall devolve on the executor or administrator of such person, in trust for the heirs at law of the deceased, in case he shall have died intestate; but if otherwise, then in trust for his devisees, in as full and ample manner, and under the same conditions, limitations, and restrictions, as the same was held, or might have been claimed or enjoyed by such person in his or her lifetime; and when application for a patent shall be made by such legal representatives, the oath or affirmation provided in the third section of the beforementioned act, shall be so varied as to be applicable to them.

SEC. 11. *And be it further enacted*, That every patent issued in pursuance of this act shall be assignable in law, either as to the whole interest, or any undivided part thereof, by any instrument in writing; which assignment shall be recorded in the Patent Office within three months from the execution thereof, for which the assignee shall pay the Commissioner the sum of ——— dollars.

SEC. 12. *And be it further enacted*, That any citizen of the United States, or alien, who shall have been resident in the United States one year next preceding, and shall have made oath of his intention to become a caveat setting forth the design and purpose thereof, and its principal and distinguishing characteristics, and praying protection of his right, till he shall have matured his invention; which caveat shall be filed in the confidential archives of the office, and preserved in secrecy. And if application shall be made by any other person within one year from the time of filing of such caveat, for a patent of any invention with which it may in any respect interfere, it shall be the duty of the Commissioner to give notice to the person filing the caveat, of such application and of such supposed interference, who shall, within two months after receiving the notice, if he would avail himself of the benefit of his caveat, file his description, spifications, drawings, and model; and if, in the opinion of the Commissioner, the specifications of claim interfere with each other, like proceedings may be had in all respects, as are in this act provided in the case of interfering ap-

PAGINATION INCORRECT

plications: *Provided, however*, That no opinion or decision of any board of examiners, under the provisions of this act, shall preclude any person interested in favor of or against the validity of any patent which has been or may hereafter be granted, from a citizen thereof, who shall have invented any new art, machine, or improvement thereof, and shall desire further time to mature the same, may file in the Patent Office the right to contest the same in any judicial court, having jurisdiction of the subject-matter.

SEC. 13. *And be it further enacted*, That whenever any patent which has heretofore been granted, or which shall hereafter be granted, shall be inoperative or invalid, by reason of a defective or insufficient description or specification, or by reason of the patententee claiming in his specification as his own invention, more than he had or shall have a right to claim as new; if the error has, or shall have arisen by inadvertency, accident or mistake, and without any fraudulent or deceptive intention, it shall be lawful for the Commissioner, upon the surrender to him of such patent, and the payment of a further duty of fifteen dollars, to cause a new patent to be issued to the said inventor, for the same invention, for the residue of the period then unexpired for which the original patent was granted, in accordance with the patentee's corrected decription and speeification. And in case of his death, or any assignment made by him of the original patent, a similar right shall vest in his executors, administrators, or assignees. And the patent, so re-issued, together with the corrected description and specification, shall have the same effect and operation in law, on the trial of all actions relative to the violation of such invention, as though the same had been originally filed in such corrected form, before the serving out of the original patent. And whenever the original patentee shall be desirous of adding the description and specification of any new improvement of the original invention or discovery which shall have been invented or discovered by him subsequent to the date of his patent, he may, like proceedings being had in all respects, as in the case of original applications, and on the payment of fifteen dollars, as hereinbefore provided, have the same annexed to the original description and specification; and the Commissioner shall certify, on the margin of such annexed description and specification, the time of its being annexed and recorded; and the same shall thereafter stand on the same footing to all intents and purposes as though it had been embraced in the original description and specification.

SEC. 14. *And be it further enacted*, That whenever in any action for damages for using or selling the thing whereof the exclusive right is secured by any patent heretofore granted, or by any patent which may hereafter be granted, a verdict shall be rendered for the plaintiff in such action, it shall be in the power of the court to render judgment for any sum above the amount found by such verdict as the actual damages sustained by the plaintiff, not exceeding three times the amount thereof, according to the circumstances of the case; and such damages may be recovered by action on the case, in any court of competent jurisdiction.

SEC. 15. *And be it further enacted*, That the defendant in any such action shall be permitted to plead the general issue, and to give this act and any special matter in evidence of which notice in writing may have been given to the plaintiff or his attorney, thirty days before trial, tending to prove that the description and specification filed by the plaintiff does not contain the whole truth relative to his invention, or discovery, or that it contains more than is necessary to produce the described effect; which conceal ment or addition shall fully appear to have been made for the purpose of deceiving the public; or that the thing patented was not originally discovered by the patentee, or had been in use, or had been described in some public work anterior to the supposed discovery thereof by the patentee, or had been in public use or sold with the consent and allowance of the patentee before his application for a patent; or that he had surrepticiously or unjustly obtained a patent for that which was in fact invented or discovered by another; or that the patentee if an alien at the time the patent was granted, had failed and neglected, for the space of eighteen months from the date of the patent, to put in operation and use in the United States, and put on sale to the citizens thereof, on reasonable terms, the invention or discovery for which the patent issued; or in case the same, for any period of eighteen months after it shall have been put in operation and use, shall cease to be so used

or put on sale ; in either of which cases judgment shall be rendered for the defendant with costs; *Provided, however*, That whenever the plaintiff shall fail to sustain his action on the ground that, in his specification of claim is embraced more than that of which he was the first inventor, if it shall appear that the defendant had used or violated any part of the invention justly and truly specified and claimed as new ; it shall be in the power of the court to adjudge and award as to costs as may appear to be just and equitable.

Sec. 16. *And be it further enacted*, That whenever there shall be two interfering patents, or whenever a patent on application shall have been refused on an adverse decision of a board of examiners on the ground that the patent applied for would interfere with an unexpired patent, previously granted any person interested in any such patent, either by assignment or otherwise, in the one case, and any such applicant in the other case, may have remedy by bill in equity; and the court having cognizance thereof, on notice to adverse parties and other due proceedings had, may adjudge and declare either of the patents void in the whole or in part, and may also adjudge that such applicant is entitled, according to the principles and provisions of this act, to have and receive a patent for his invention as specified in his claim, or for any part thereof, as the fact or priority of right or invention shall in any such case be made to appear. And such adjudication, if it be in favor of the right of such applicant, shall authorize the Commissioner to issue such patent, on his filing a copy of the adjudication and otherwise complying with the requisitons of this act. *Provided, however*, that no such judgement or adjudication shall effect the rights of any person except the parties to the action and those deriving title from or under them subsequent to the rendition of such judgment.

Sec. 17. *And be it further enacted*, That all actions, suits, controversies, and cases arising under any law of the United States granting or confirming to inventors the exclusive right to their inventions or discoveries, shall be originally cognizable, as well in equity as at law, by the circuit courts of the United States, or any district court having the powers and jurisdiction of a circuit court, which courts shall have power, upon bill in equity filed by any party agrieved in any such case, to grant injunctions according to the course and principles of courts of equity, to prevent the violation of the rights of any inventor as secured to him by any law of the United States, on such terms and conditions as said courts may deem reasonable ; *Provided, however*, That from all judgments and decrees of any such court rendered in the premises, a writ of error or appeal, as the case may require, shall lie to the Supreme Court of the United States, in the same manner and under the same circumstances, as is now provided by law in other judgments and decrees of circuit courts. and in all other cases in which the court shall deem it reasonable to allow the same.

Sec. 18. *And be it further enacted*, That there shall be provided for the use of said office, a library of scientific works and periodical publications, both foreign and American, calculated to aid and facilitate the discharge of the duties hereby required of the chief officers therein, to be purchased under the direction of the Committee of the Library of Congress. And the sum of ——dollars annually is hereby appropriated for that purpose, to be paid out of the patent fund.

Sec. 19. *And be it further enacted*, That it shall be the duty of the Commissioner to cause to be classified and arranged, in such rooms or gallaries as may be provided for that purpose, in suitable cases, when necessary for their preservation, and in such manner as shall be conducive to a benficial and favorable display thereof, the models and specimens of compositions and of fabrics and other manufactures and works of art, patented or unpatented, which have been or shall hereafter be deposited in said office. And said rooms or galleries shall be kept open during suitable hours for public inspection.

Sec. 20. *And be it further enacted*, That all acts and parts of acts heretofore passed on this subject be, and the same are hereby, repealed : *Provided, however*, That all actions and processes in law or equity sued out prior to the passage of this act, may be prosecuted to final judgment and execution, in the same manner as though this act had not been passed, excepting and saving the application to any such action, of the provisions of the fourteenth and fifteenth sections of this act, so far as they may be applicable thereto.

INTRODUCTION.

There exists no special work on Locomotive Engines. Two writers, Wood and Tredgold,* have indeed, in England, slightly touched upon that matter, but only in a subordinate manner, in treatises on railways; and besides, they both wrote at a time when the art was scarcely beyond its birth. Consequently their ideas, their calculations, and even the experiments they describe, have hardly any relation to the facts which actually pass before our eyes, and can be of no use to such as wish to acquire a knowledge of these engines and their employ on railways.

Many questions had not even been entered into, others had been solved in a faulty manner. New researches on the subject became therefore indispensable. This work will, in consequence, be found completely different from any thing that has been published hitherto. No facts will be quoted, but such as result from actual observation; no experiments related, but those made by the author himself, on a new plan and with new aims; finally, no theory exposed but such as is derived from those experiments.

If at first sight it appear astonishing that no theory of Locomotive Engines should exist, the surprise ceases on considering that the theory of the steam-engine itself, taken in general, has not yet been explianed. It was natural to suppose, that, respecting a machine at present in such universal use, and on a subject of such importance, every thing had been said, and every explanation given long ago. Far from this being the case, however, not even the mode of action of the steam in these engines has been elucidated. In the absence of such indispensible knowledge, all theoretical calculations were impossible. Suppositions were put in the place of facts. In consequence, we have seen very able mathematicians propose, on the motion of the piston in steam engines, analytical formulæ, which would certainly be exact, if all things went on in the engine as they suppose; but which not being founded on a true basis, fall naturally to the ground, in presence of facts.—From this also results that, in practice, the proportions of the engines have only been determined by repeated trials, and that the art of constructing them has proceeded hitherto in the dark, and by imitation.

Locomotive Engines being first of all steam-engines, we cannot advance in the researches we undertake, without solving at the same time the question relating to steam-engines in general. There is even a remarkable point to be observed, which is, that of all sorts of steam-engines, locomotive ones are those which in their application have to overcome the least complicated resistance, and the most susceptible of a rigorous appreciation. This circumstance renders them therefore more proper than any others, for furnishing an explanation of general facts common to all those machines. The theory once satisfactorily established in regard to Locomotive Engines, will of course, apply equally to all sorts of steam-engines, and more especially to those which, like locomotive ones, work at a high pressure.

We flatter ourselves, therefore, that our researches, although apparently confined to Locomotive Engines, may at the same time illustrate he principal points of the theory of steam-engines in general.

However, in order to indicate clearly the

* "A Practical Treatise on Railroads, and Interior Communication in general, by Nicholas Wood." First edition, London, 1825; 2d edition, London, 1832.
"A practical Treatise on Railroads and Carriages by Thomas Tredgold," London, 1825.

design of this work, and to show in what it differs from those that have preceded it, we think proper to enter here into some particulars as to the points on which we have new researches to offer, either theoretical or experimental. It will be seen that those points embrace nearly the whole subject.

The pressure of the steam in the boiler, had been till now considered as invariable in every engine. It was calculated once for all, and by approximation, according to the weight on the valve. A great number of observations will show, however, how much it varies during the motion of the engine, and how necessary it is to take that circumstance into consideration, and to make use of a more exact mode of determination, lest the calculation should be entirely founded on an erroneous basis.

On that subject there will be found in our work, an alteration we propose making in the present disposition of the spring-balance, in order that it may show the true pressure; and also the description of a portable instrument we suggest for superceding the mercurial guage, and which may be adapted to any engine.

The friction of the wagons was, until now valued much too high. This error naturally rendered every calculation false, by misleading with regard to the true resistance overcome by the engines. A great number of experiments on wagons, with or without springs, alone or united in considerable trains, will show the real value of the friction.

The resistance of Locomotive Engines was still an unsolved question. We have endeavored to determine it by three different processes, which may serve to verify each other.

The additional friction created in the engine by the load it draws, had never yet been submitted to any investigation. We shall present numerous experiments on that subject.

The exact determination of the pressure of the steam in the cylinder, was necessary to explain the mode of action of Locomotive Engines, as well as that of steam-engines in general, and to calculate the work they perform in different circumstances. The erroneous ideas admitted in that respect, were the origin of all the faulty calculations, which experiment contradicted. We trust that the simple elucidation of that point will in a manner lay open the whole play of the engine.

The evaporating power of the engines was an element on which no experiment had yet been made, which was not even introduced in the calculations, and on which, however, definitely depends the effect these engines are able to produce. Experiments made on that subject, upon a great number of engines, will be found in this work.

An analytical equation, that might be adapted to solve the general problem of Locomotive Engines, was entirely wanting; that is to say, an equation by which might be known a *priori*, either the effects resulting from the given proportions of an engine, or, *vice versa*, the proportions that ought to be adopted, in order that predetermined effects in regard to load or speed may be obtained. The trials hitherto made to come to a solution of this question, being founded on a false principle, had produced formulæ in evident contradiction with facts. A rule had even been adopted, according to which the practical power of an engine was considered as equal to the third part only of its calculated or theoretical power; whereas, the whole applied power must evidently appear in the effect produced, and we shall see that it really does appear in it. This imaginary rule is a sufficient proof of the error of the calculations that were used, and could only lead to disappointments in practical applications. Engines were constructed, but the effect that they would produce was unknown. By the introduction of a new element of calculation, wrongly neglected until now, viz the evaporating power of the engines, it will be seen that that question is solved in the most simple manner possible. From that equation, and simply by measures taken on the machine, the velocity and load of a Locomtive Engine may be immediately found, and *vice versa*, the proportions which ought to be given to it, to make it answer any intended purpose. A great nnmber of experiments, made in a daily practice, will show the accuracy of the formulæ. This is, at the same time, the theory of all high-pressure steam-engines.

Several secondary dispositions of the mechanism of the engines had not yet been studied. It will, however, be seen that they are apt to deprive the machine of as much

as a fourth part of its power. The effects of these dispositions, and in particular of that which is called the *lead of the slide*, will be submitted to calculation, and the results verified by special experiments.

The resistance proper to the curves of the railway deserved also to fix our attention. We shall endeavor to fix accurately the form of the wheels, and the disposition of the rails, by which that resistance may most effectually be remedied.

The consumption of fuel according to the load had not been determined in a satisfactory manner, and the rule proposed was contradicted by the experiment. This question will be established in a different manner, and the results confirmed by facts.

The researches on those points were made on twelve different engines, and numerous experiments were undertaken on each branch of the subject.

The method constantly followed consists in taking, first, the primary elements of the question from direct experiment; then making use of those elements to establish a calculation in conformity with theoretical principles; and, lastly, submitting the results to fresh and special experiments, in order to obtain their verification. For the further elucidation of the formulæ, they are each time carefully submitted to particular applications, and, finally, to extend the use of the work to persons who may wish to find the results without calculations, each of these formulæ is followed by *practical* tables, suitable to the cases which occur the most frequently in practice.

It does not enter into the plan we have traced ourselves, to give an elaborate description of the engine, nor the measures of its different parts, except those necessary for the researches we undertake. Such considerations would lead us too far, and concern more particularly works on construction. In like manner, the figures added to our work, are only meant as illustrations of the text. They would be too imperfect for any other object.

The untrodden path in which we have been forced to enter, may have led us into some error. We by no means pretend to have produced a perfect work, and we claim indulgence for the mistakes which may have escaped us in so new a subject. Our chief aim was to be useful, while seeking a study congenial to our taste, and occupying the leisure of an inactive life. Early devoted to other pursuits, belonging to a family for several generations engaged in the military career, and the son of a General of Artillery, whose footsteps had naturally traced our direction, our studies would not have taken that turn, had we not been struck by the powerful effects of the moter we are going to describe, and by the important part it must necessarily act in modern civilization. We thought our work would at least have this result, to call the public attention on the subject. We shall feel happy if we have succeeded in some of our researches; and happy also if others, in correcting our errors, shall at least elucidate the facts upon which we have called their attention.

All the experiments related in the work were made by *ourselves*, with all the care and attention they required. Some were made in company with engineers of known talent and ability, as Mr. J. Loke, of the Grand-Junction Railway, and Mr. King, of the Liverpool Gas-Works. We give them in all their details, with a view that every one may judge of their accuracy; and we mention the place and date of each experiment, in order to facilitate their verification by referring to the books, on which is registered the weight of each of the trains.

In regard to the facility we had of making these numerous experiments, we must say that, having applied to the heads of the most important undertakings of the sort in England, we were permitted, without restriction, to penetrate into the workshops, to take every measure, to collect all the documents concerning the expenses, and lastly, to make any experiment that appeared necessary to us.

It is with pleasure we acknowledge in the English character the liberaltty we have found in the whole course of our investigations.

To the friendship of Mr. Hardman Earle, one of the directors of the Liverpool and Manchester Railway, we owe in particular our warmest thanks. His obligingness never abated. Possessing all the qualities of an enlightened mind, he liked taking a part in researches which appeared to him conducive to the progress of sci-

ence; and he permitted us to use all the engines and wagons of the railway. The beauty of these engines, their number, which is not less than thirty, the care with which they are kept, and the immense trade on that line, which gives the facility, without interfering with the business of the railway, to select loads for experiments as considerable and as light as one wishes, make that place the only one, perhaps, in the world, where experiments on a great scale may be made with the same precision as in general can only be obtained by a small apparatus. It is for that reason we preferred that railway to any other at present in activity, either in France or in England.

The same facilities were also offered us by the directors of the Darlington Railway. Interesting documents concerning the repairs and expenses of all sorts, incurred by that company, were obligingly communicated to us. We owe that obligation to the liberal authorisation of Mr. J. Pease, M. P., chairman of the company, and the unremitting attentions of Mr. Robert B. Dockray.

We have studied the subject with all the interest, and, we might say, with all the enthusiasm it excited in us. In fact, what a subject for admiration is such a triumph of human intelligence! What an imposing sight is a Locomotive Engine, moving without effort, with a train of 40 or 50 loaded carriages, each weighing more than ten thousand pounds! What are henceforth the heaviest loads, with machines able to move such enormous weights? What are distances, with moters which daily travel 30 miles in an hour and a half? The ground disappears, in a manner, under your eyes, trees, houses, hills, are carried away from you with the rapidity of an arrow; and when you happen to cross another train travelling with the same velocity, it seems in one and the same moment to dawn, to approach, and to touch you; and scarcely have you seen it with dismay pass before your eyes, when already it is again become like a speck disappearing at the horizon.

On the other hand, how encouraging is the evident prosperity of those fine establishments. How satisfactory it is to acquire the proof that the Liverpool Railway produces 9 per cent. interest, and the Darlington one an equal profit! With what confidence must we not anticipate the future state of such undertakings, when we know that, besides the above-mentioned annual interest, the shares of the Liverpool Railway have risen, in four years,* from £100 to £210; and those of the Darlington Railway, in eight years, from £100 to £300? What may not society at large expect in future from this new industry, which will augment, ten-fold, the capital and produce of the country, by the immense influence of speedy and economical conveyance!

We shall in the course of the work make use of the following abbreviations:—

Ton	t.
Pound avoirdupois . .	lb.
Foot	ft.
Square foot	sq. ft.
Cubic foot	c. ft.
Inch	in.
Pound sterling . . .	£.
Shilling	s.
Penny	d.

* The first edition of this work appeared in French, in the beginning of 1835.

A

PRACTICAL TREATISE ON LOCOMOTIVE ENGINES.

The plan we intend to follow in the course of this work will, we hope, render it both clear and methodical.

We shall begin by the description of a locomotive engine; and we shall acquaint the reader with the means by which the pressure of the steam may be accurately measured, so that, before we go any father, he will be able to see the elements from which the power of the mover we are to employ is derived.

Our attention will afterwards be directed towards the resistances which that mover must overcome in its motion, so that we shall successively endeavour to discover as well the resistance of the waggons, as that which belongs to the engine itself, either when it moves alone, or when it draws a load after it.

These points first established, we shall pass to the general theory of the movement of locomotive engines, and we shall lay down the formulæ by which to determine, *a priori*, either the speed the engine will acquire with a given load, the load it will draw at a given speed, or the proportions which are to be adopted in its construction to make it answer any intended purpose.

After that, we shall have to consider several additional dispositions proper to the engine, which may exereise more or less influence on the expected effect; and we shall then also treat of some external circumstances, the result of which may be of the same nature.

Lastly, we shall speak of the fulcrum of the motion, or of the force of adhesion of the wheel to the rails; and our last chapter will contain a calculation of the quantity of fuel required for the traction of given loads.

These inquiries will be sufficient to solve all the most important questions concerning the application of locomotive engines to the draft of loads.

They will sometimes be necessarily subdivided into several branches, and require calculation and theoretical illustrations of more or less extent, though always plain and easy, and a series of experiments more or less numerous; but we shall take care to maintain, all along our work, the classification we at present lay down.

CHAPTER I.

DESCRIPTION OF A LOCOMOTIVE ENGINE.

ARTICLE I.

ENUMERATION AND DESCRIPTION OF THE PARTS.

Figure 1 represents a locomotive engine constructed on the most approved principle. Its mechanism is so simple, that a short description will be sufficient to explain its mode of acting. Whatever may appear unsatisfactory in this first sketch, will be cleared up by the particulars we shall have occasion to add in the course of the work.

The principal parts of the engine are: the fireplace and boiler, which constitute the means of raising the steam; the slides and cylinders which are the means of bringng into action the elastic force residing in that steam; and the cranks and wheels, by means of which the motion is transferred from the piston to the engine itself. When we have described those principal parts, we shall pass to some others of less importance, and then we shall fix the particular place each of those parts occupying in the engine.

§ 1. *Of the Boiler.*

Figure 3 gives a complete idea of the boiler.

It shows the body of the machine, composed of three distinct compartments. The one to the right, or fronting the machine, and which is surmounted by the chimney C, is separated from the two others by a partition *tt*, The two others together form the boiler. Both are filled with water to a certain height *cd*, but part of their internal space is occupied by the fire, as will be explained.

In the hindmost compartment is placed a square box *e*, which contains the fuel, or forms the fireplace of the machine. Between the sides of that box and those of the compartment in which it is contained, a space *qq* is left, which communicates freely with the remainder of the boiler, and which is consequently filled with water. The inner box is supported in the compartment in which it is contained, and joined to it by strong bolts, having the advantage of giving solidity to that part of the boiler which, not being rounded, offers less resistance than the cylindrical parts.

The fire-box *e*, being thus placed in the middle of one of the compartments of the boiler, would be surrounded on all sides with water, were it not for the aperture *l*, which forms the door of the fire-place, and the bottom, *nn*, of the box which is occupied by a grate, one of the bars of which is represented at *nn*. This grate is more plainly seen in fig. 4 which represents the same fire-box seen in front.

Near the door *l*, and in the machine, is placed a strong supporting board, represented in fig. 1, by BB. The use of this board is for the engine-man to stand upon. Directly behind the machine comes the tender carriage for coke and water, so that it is easy for the fireman to throw coke in the fire by the door *l*, and to let water pass in the boiler whenever it may be necessary. This supply of water takes place by means of a forcing-pump, put in motion by the engine itself, and of which we shall speak hereafter.

The lower part, *nn*, of the fire-place is occupied, as we have said, by a grate, and remains consequently open, admitting the external air required for the combustion of fuel. The coke thrown into the fire-box, falls on the grate and is supported by it. When the fire is lit, and the door of the fire-box shut, the flame of the combustible remains confined in the fire-box. It would have no egress, if a number of small tubes or flues *e e'*, the disposition of which is better seen in fig. 4, were not to lead the flame to the chimney, after passing through the whole length of the second compartment or cylindrical part of the boiler.

From that construction it will easily be conceived, that the fire being shut up in the fire-box, and completely surrounded with water, none of its calorific parts are lost. Afterwards, the flame, in its way to the chimney, divides itself among all the small flues we have mentioned. It crosses thus the water of the boiler, having a considerable surface in contact with it, and only escapes after having communicated to the water as much as possible of the caloric it contained. Once arrived at the extremity *e''* of the tubes, the flame is in the compartment of the chimney, and escapes freely through the chimney C.

We see thus the heat applied here in two very distinct manners. All the water which surrounds the fire-box is in immediate contact with the fuel, and consequently subject to the action of the radiating caloric; on the contrary, the water which is placed in the middle compartment, receives its heat only from the contact of the flame and heated air which escape from the fire-box, so that it is exposed only to communicative heat.

It may be necessary to observe here, that the form of a boiler, with tubes, a form to which is undoubtedly owing the surprising power of the present locomotive engines, is a French invention. This ingenious idea belongs to M. Seguin, civil engineer and manufacturer in Annonay.*

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* M. Seguin's patent bears the date of the 22d of Feb. 1828; and it was not until April 25, 1829, that the committee of directors of the Liverpool Railway called the attention of the English mechanicians towards locomotive engines, by proposing a prize on the subject. On October 6, of the same year, 1829, and not before, appeared the ROCKET engine of Messrs. Stephenson and Booth, the principle and even the form of which differ in no way from M. Seguin's patent. We do not wish to detract from Mr. Booth's merit in having also conceived that happy idea. It is not the first time that two ingenious persons have had the same thought; but, by the above-mentioned dates, it will be

§ 2. *Of the Action of the Cylinders.*

The second important part of the engine is the apparatus of slides and cylinders. Fig. 3 is also desinged to show the disposition of this part.

In the upper part of the boiler, that is to say, in the part occupied by the steam, there is a large tube VV′, which is open at one of its ends and leads out of the boiler. It is by this tube that the steam is conducted into the cylinders. At V′, in the interior of the tube, is a cock or regulator, the handle T of which extends out of the machine. By turning that handle more or less, the passage for the steam may be opened or shut at will.

The steam, being thus generated in great abundance in the boiler, and being unable to escape out of it, acquires a considerable degree of elastic force. If at that moment the cock V′ is opened, the steam, penetrating into the tube by the aperture V, follows it to the entrance *v* of the valve-box. There a sliding valve *x*, which moves at the same time with the machine, opens a communication to the steam successively with each end of the cylinders. These are placed horizontally at the bottom of the chimney compartment, where the passage of the flame and the sides of that compartment protect them against the condensating effect of the cold air, and keep them in a proper degree of heat.

The direction of the arrows in the figure mark the line of circulation followed by the steam, from its entrance at the aperture V, into the slide-box. In the situation in which the slide is here represented, passage 1 is open to the steam, and consequently the piston is pushed in the direction of the arrow. At the following instant, passage 2 will be open in its turn, and the piston will be pushed in the contrary way. When the steam has produced its effect, it passes in the tube *v′*, and is conveyed by it to the chimney, through which it escapes into the atmosphere.

The introduction of the steam takes place at V, at a point purposely elevated, that the bubbling and jolting of the engine may not let the water of the boiler get in by the opening V.

§ 3. *Of the Cranks and Wheels.*

The piston-rods being set in motion according to the foregoing explanation, and sliding in guides which prevent any deviation from a rectilinear horizontal motion, communicate a rotatory movement to the axle of the two hind wheels of the engine. This transformation of the alternate motion into a circular one, takes place after the manner of the common foot spinning-wheels, by means of a crank in the axle. This effect is clearly represented in fig. 3. There the steam may be seen forcing alternately the piston backwards and forwards, and turning the crank *yz*, and at the same time the axle and the wheel which is fixed to it. However, as in the motion of a crank, there are two points in which the alternate force that puts the crank in motion, has no greater tendency to move it in one direction than in another, which takes place whenever the radius of the crank happens to be on the centre, that is to say, in the direction of the alternate motion; the two cranks respectively corresponding with the two pistons, are placed at right angles to each other. By that means one of the two has always its full effect whenever the other ceases to act, and the power of the engine never varies. The two cylinders being, as we have already said, placed beneath the boiler, the piston-rods communicate directly under the engine with the above-mentioned cranks as appears in the figure. The crank-axle being set in motion, the wheels, which form one body with it, turn at the same time and, the engine is propelled in the same manner as a carriage which would be set a-going by turning the wheels round by the spokes.

The only fulcrum of the motion being in the adhension of the wheels to the rails that support them, which adhension causes them to advance instead of slipping round, it

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seen that the prior claim rests, nevertheless, with the French engineer.

The fact may be easily verified in England, by looking for a description of the patent in some of the following works, which are certainly to be found in the British Museum and other chief English libraries: Annales de l' Industrie Francaise et Etrangere, ou Recueil Industriel et Manufacturier, annee 1828; Bulletin de la Societe d' Encouragement pour l' Industrie Nationale, annee 1828; Description des Machines et Procedes consignes dans les Brevets d' Invention, de Perfectionnement et d' Importation, publiee d' apres les Ordres du Ministre de l' Interieur et du Commerce. This last work we quote in advance, as it only gives the description of expired patents: M. Seguin's will not be mentioned until the year 1838.

might appear doubtful whether, on such an even surface as the rails of a railroad, the engine could advance by means of the sole rotatory movement imparted to its wheels, particually when the engine has to draw a considerable weight. But experience proves that however slight the adhesion of a wheel to a well-polished rail may appear to be, as, on the other hand, the power required to draw a load on a railroad is very small, that adhesion is sufficient, and the engine progresses, followed by its whole train.

In ordinary cases, the adhesion of two wheels is sufficient; particularly with engines, the weight of which is distributed so that the drawing-wheels bear about the two-thirds of it. When a great power of adhesion is required, the four wheels are made equal. In that case one may, if necessary, connect the two wheels of the same side together, by metallic rods placed on the outside of the wheels. One of these connecting-rods is represented in fig. 6. C is the prolongation of the axle beyond the wheel. The crank-arm C*o* is fastened to that prolongation of the axle, and must necessarily turn with it. The point *o* is a ball and socket joint; *m* is a cotton-wick syphon, by which the oil is fed in the joint; *nn* are keys designed to lengthen or shorten the rod, which at its opposite end is joined in the same manner to the crank-arm of the other wheel. The natural result of this is, that when the wheel or the axle C turns, it carries along with it the crank-arm C*o*, and thus communicates the same motion to the other extremity of the connecting-rod, and by it to the crank-arm of the second axle. Thus the power of the engine is communicated by the two hind wheels to the two others, and the engine then adheres by its four wheels.

In order that, while in motion, the engine may not slip off the rail, which, we know, are iron bars projecting above the ground, the wheels have, on the inner side, a flange that prevents any lateral motion. But as, on the other hand, that flange ought not to be in danger of constantly rubbing against the side of the rail, the tire of the wheel is not exactly cylindrical, but slightly conical. Its diameter is a little larger on the side of the flange than on the outward side; the consequence of which is, that, supposing the engine were to be for a moment pushed to the left, the left wheel, resting on its broadest part, would pass over more way than the right wheel, and by that means bring the engine back to its true place between the rails. Wheels of such a form may be seen in fig. 2.

§ 4. *Of the Safety Valves.*

The three preceding points form the foundation on which the action of the engine rests; the other parts are only secondary ones, that is to say, only designed to make the power produced by the former ones efficient. The boiler has two safety-valves E, F (fig. 1), one of which is sometimes shut up in a box, to put it out of the reach of the engineman, and to prevent him from overcharging it, as he might be tempted to do in order to obtain from the engine a greater effect, even at the risk of damaging it. More commonly, however, that precaution is given up, on account of its inconvenience.

§ 5. *Of the Water-Gauge.*

A gauge is likewise fixed to the machine to show at what height the water stands in the boiler. This gauge is a glass tube, *mn* (fig. 7,) inchased at both its ends in two verrels *aa*, with cocks communicating with the interior of the boiler and appearing outside, as may be seen in the figure. When the two cocks *rr* at the top of the tube are opened, the water penetrates into the tube and takes the same level as in the interior. The cock S is designed to let that water afterwards run off. The use of this instrument is, that the engine-man may know when it becomes necessary to let the apparatus be refilled from the tender. As, however, the tubes and other parts of the boiler begin to suffer, that is to say, are apt to crack, when the water gets too low in the machine, there are, for more safety, on the side of the boiler, two and sometimes three small cocks, placed at different heights; by opening which, one after the other, the level of the water in the interior may be still more positively ascertained. If it be necessary to know at what height the water stands in the boiler, it is not less so to be certain of the real degree of elastic force the steam possesses; for, should that force not be sufficient, the engine would be unable to accomplish its task: but as this point

requires to be explained at some length, we shall at a further period make it the subject of a chapter by itself.

§ 6. *Of the Slides.*

We have another important object to clear up. We have said above, that the slide-valve admits successively the steam above and below the piston of each cylinder, the result of which is the alternate motion, source of the final progressive motion of the engine. The engine-man then having opened the regulator or cock that admits the steam into the pipes, the steam proceeds from the boiler through the tube *v*, (fig. 8) to the valve-box, and, pressing with all its force on the upper part *x* of the sliding-valve, compels it to remain in immediate contact with the plane in which it slides, while performing its motion. When the slide is in the situation in which it is represented in the figure, the steam takes the way marked 1, acts upon the piston, and pushes it in the direction of the arrow. In the meanwhile, the steam under the piston escapes through the passage 2, which then communicates with the exterior, by means of the aperture *e*. When this first effect has been produced, the slide, by means of its rod *l*, is pushed in the position marked by the dotted lines. Then, on the contrary, it is the passage 2 which is open to the steam coming from the boiler: it pushes, consequently, the piston in the opposite direction to its first motion; while the passage 1, communicating in its turn with the aperture *e*, gives free egress to the steam that has produced its effect. The alternate motion continues thus: the slide passing from one position to the other, by which it opens and shuts successively the passages, so that the steam may act alternately above and below the piston. The steam is afterwards led to the chimney, as will be explained hereafter, there to augment the current of air by which it causes the draft of the fire.

The motion of the slide is regulated so as to accompany the motion of the piston, but still to precede it by a very short instant: that is to say, that instead of opening the proper passage for the stroke of the piston just at the moment the piston is going to begin that stroke, it opens it a little beforehand. This is called giving a little *lead* to the slide. By that means, at the moment the piston begins its motion, the steam has already its full action upon it. We shall have occasion to come back to this point, when we shall see that this disposition, which is favorable to the speed of the engine, can be advantageously employed only within certain limits, beyond which it would be prejudicial to the load the engine is able to draw.

§ 7. *Of the Eccentric Motion.*

The alternate motion of the slide is performed by the steam itself. To comprehend this point requires some attention.

An eccentric wheel is fastened to the axle, and, as this turns, the eccentric, drawn along by its motion, pushes and draws alternately the rod of the slide.

This effect is represented in figs. 9 and 10. The point O is the centre of the axle, of which the section appears hatched. The point *m* is the centre of the eccentric, hatched in a contrary direction. The axle, in turning, draws the eccentric along with it, and makes, consequently, the point *m* describe a circle round the point O. In that motion the point *m*, passing successively to the right and to the left of the centre O, must necessarily, by means of the ring *nn*, which encircles the eccentric, push and draw alternately the shaft L, which acts upon the slide.

On the other hand, the point C representing the extremity or throw of the crank of the axle, which is set in motion by the piston, it will appear that when the steam-pushing the piston from one end of the cylinder to the other, makes the crank revolve half way round, the axle makes also the half of a revolution round itself; so that the point *m* describes the half of a circumference round the point O, and consequently the eccentric pushes the shaft L, and by it the slide-rod *l*, from one of their extreme positions to the other.

Thus placed, by this first operation, the slide now admits the steam on the opposite side of the piston. The piston then goes back, makes the axle revolve again half way round, whereby the slide is brought back to its original position, which suits the next stroke of the piston; and so forth.

The effect of drawing and pushing altenrately the slide-rod by means of the ro-

tation of the eccentric, is accomplished by means of a metallic ring *nn* fixed at the end of the shaft L, and in which the eccentric-wheel turns, the surfaces which are in contact being smooth and lubricated with oil. By this arrangement, while the great radius of the eccentric passes in turning from one side of the centre to the other, it carries along with it the shaft fastened to the ring, and communicates to that shaft the alternate motion.

By this it will be seen that the eccentric wheel acts here the part of a common crank for transforming the circular motion of the axle in an alternate motion applied to the slide, on the contrary principle to that which changes the alternate motion of the piston into a circular motion applied to the axle of the engine ; but the eccentric dispenses with the crank which would have been necessary in the axle.

However, as by the disposition of the engine the slide-rod is not in the same plane with the axle, the eccentric does not communicate directly the motion to the slide-rod itself ; the motion is communicated to that rod by means of the cross-axle K, and the two arms KL′ and K*l*′ which are fixed to it ; and the consequence is, that when the eccentric goes back, the slide-rod *l* advances, and *vice versa*, as may be seen on the figure.

A comparison between figs. 9 and 10, the difference of which is a quarter of a revolution, will make the above mentioned effects perfectly intelligible.

By examining the motion of the slide (fig. 10.,) it will be seen that, while passing from one of its situations to the other, and when it happens to be exactly in the middle position, there occurs one instant during which all the passages of the steam are shut together. This effect takes place at the moment the slide changes the passages of the steam, and corresponds with the point where the piston changes its direction. This coincidence can only take place because, setting aside the little lead of the slide, the radius of the eccentric is at right angles with the radius of the crank. In fact, the slide is necessarily thus in its middle position, that is to say, changing the communications of the steam, at the same time as the piston is at the bottom of the cylinder, ready also to alter the direction of its motion. This correlativeness of motions is clearly exhibited in the figure.

The particular advantage of the eccentric being thus placed at right angles with the crank is, that the eccentric is in full action when the crank is on its centre, or the piston at the bottom of the cylinder, that is to say, that the slide is in its most rapid motion just at the moment that it is to open or shut the passages ; which circumstance is necessary to prevent time being lost in the alternate effect of the steam.

§ 8. *Of the Drivers.*

Until now we have spoken as if there were only one slide, but, having said there were two cylinders, it is clear that there must be a slide, and consequently an eccentric for each of them On the other hand, the two pistons alternating one with the other in their motion, that is to say, acting upon two cranks perpendicular to each other, as hss been explained, the radii of the two eccentrics must necessarily stand also at right angles with each other. This disposition may be seen in figs. 11 and 12, where the piece forming the two eccentrics is represented in front. To make it more clear, it is marked by hatchings.

This piece must, as has been said, move with and be carried along by the axle.—However, if it were permanently fixed on the axle, its position might suit when the engine is to go forward, and not when it is to go backward ; for it will be seen that, for these two motions, the eccentric must be fixed in two different positions.

This piece is therefore loose upon the axle like a pulley on its axis, but it can be fastened to it at will. To that effect its side-faces have two apertures or eyes, represented at O and O′ ; and the axle itself carries two pins *rr*′, which are called drivers. The eccentric being placed on the axle between the two drivers, it is easy to push it by means of a lever, either against one or against the other, until it enters the aperture designed for it ; so that from that moment, the eccentric may be drawn along by the axle. Moreover, if these two drivers be placed in such a manner that one may suit to the progressive, and the other to the retrograde motion of the engine, we shall, by disengaging the eccentric from the one and carrying it to

the other, be enabled to make the engine go either forward or backward at pleasure.

There is no difficulty in fixing the place that the eccentric must occupy on the axle either for the progressive or the retrograde motion.

Let us suppose that, by pushing the engine gently along the rails, we bring one of the pistons to be just in the middle of the cylinder, and that precisely at the same instant the crank, on which that piston acts, is in its verticle position above the axle, as in fig. 3, it is clear that, to make the engine go forward, the steam must push the piston forwards, for then the piston will carry along with it, in the same direction, both the crank and the wheels; consequently, the slide must must admit the steam by the passage No. 1, or be drawn forward as it is represented here, which, by referring to fig. 9, requires that the radius of the eccentric be horizontal, and placed at the back of the axle. This is, therefore, the point at which the driver must fix the eccentric for the progressive motion.

The engine remaining in the same position, let us suppose that we wish on the contrary, to dispose it for the retrograde motion. The steam must arrive on the opposite face of the piston, that is to say, that the passage No. 2 must be opened to it, which supposes that the slide is pushed backwards, and consequently that the eccentric is in front. It is therefore horizontally, and in the front of the axle, that the eccentric must be fixed by means of the driver.

This is exactly the position of fig. 12. By observing the right hand crank, we see that while that crank is vertical and above the axle, the driver *r* on the right side, and the aperture that receives it, are behind and hidden by the axle; consequently, the eccentric is horizontal, and in front; a position which, as we have seen, suits a retrograde motion. The driver *r* is thus placed for the retrograde motion, keeping the eccentric in that position.

If we now suppose, on the contrary, that the eccentric be pushed against the other driver *r'*, the corresponding aperture of the eccentric being at O', that is to say, not being in front of the driver, the consequence will be that, the eccentric not stirring out of its place, the axle will be forced to turn half round before the driver can enter into the aperture. From this follows, that, if we continue to examine the right crank, it will be found to have arrived *under* the axle, while the eccentric will still be in front, which is the position that suits the progressive motion; for it is the same as the one we have explained above, of the crank being above the axle, and the eccentric behind.

Thus we see that the two driver *r'* and *r*, in figs. 11 and 12, being placed at right angles with each other, and with the cranks of the axle, are in a proper position; one for the progressive, and the other for the retrogade motion of the engine.

These two drivers being fixed on the axle, one on one side, and the other on the other side of the eccentric, it is clear that, by pushing that eccentric, by means of a lever, either on one or on the other of the two drivers, the effect of the steam on the piston will immediately be to carry the engine either forwards or backwards, according to the driver with which it has been thrown in gear. The lever, which causes the change of position of the eccentric, is placed in such a manner as to present its handle within the reach of the engine-man, on the board on which he stands.

Besides these several dispositions, in order that the man who directs the engine may himself and of his own accord move the slides, independently of the motion of the axle, the shafts of the eccentrics are not invariably fixed to the slide rods. They are only fastened to them by a notch L', figs. 13 and 14. By means of a lever acting on the small rod *m' o*, the engine-man can raise the shaft of the eccentric and disengage it from the the notch, as may be seen in fig 14; then the slides are at liberty to move independently of the axle; consequently, it is easy by means of two handles represented by PP in fig. 1, and connected with the slide-rods, to give to those slides the required motion.

§ 9. *Of the Water-Pumps.*

Under the body of the engine are two pumps *p*, fig. 1. the use of which is to replenish the boiler with water. Each of them is placed immediately under the piston-rod of each cylinder, and is worked by it. Each pump sucks a part of the water of the tender into the cylinder of the pump, and, on the other hand, forces it from the

cylinder of the pump into the boiler, in the usual way. By having two pumps the replenishing of the boiler is secured, as, in case one of the two were to get out of order, the other may easily supply its place.

The valves of these pumps are ingeniously made of a small metallic sphere, resting on a circular seat, on which it exactly fits. Their action takes place by rising within a cylinder, the sides of which are pierced with four apertures for the passage of the water. One of these valves is represented in fig. 15. The water is introduced through *a* from the interior of the cylinder under the sperical ball which it raises, and is diffused in the body of the pump by the apertures *b*, *b*. This form of a valve never misses its effect; and the pumps, which, in the beginning, were continually out of order, are free from that defect, since Mr. Melling of Livepool first introduced that sort of valve.

§ 10. *Of the Steam-Regulator.*

The regulator, of which we have spoken above, and by means of which the passage leading from the boiler to the cylinders may be more or less opened, is represented in figs. 32 and 33. It simply consists of two metallic disks placed above and exactly fitting each other, both having an aperture of the same size. The inferior disk is immoveable, and shuts the pipe through which the steam escapes. The superior disk is moveable, by means of a handle T, which projects out of the engine; the stem *r* of the handle passes through the moveable disk, and enters the other in its centre, so as to keep them both in a right position over each other. In fig. 32, these two disks are distinguished from each other by hatchings running a different way. By making the superior disk K, by means of the handle T, move circularly on the inferior disk, the two apertures may be brought to correspond exactly with each other, as in fig. 32, and then the passage is entirely open. If only partially moved, as represented by the dotted lines in fig. 33, the passage is only partially opened; and when the two apertures do not correspond at all, the communication is completely intercepted: when the passage is thus shut, it is the steam itself that keeps the two disks in immediate contact with each other, by pressing with all its force on the superior disk.

This regulator may also be constructed in a different way. It is sometimes made in the form of a common two-way cock, the steam coming from above; but the preceding description is the one most commonly used.

§ 11. *Of the Joints or rubbing parts.*

In all the joints of any importance, the oil is fed without interruption by means of a cup, with a wick-syphon, placed above the joint, as at *m* in fig. 6. This cup is made in the form of a school-boy's inkhorn, so that the velocity of the motion may not spill the oil; and there is at the bottom of it a small tube, penetrating to the entrance of the joint. A cotton-wick dipping in the oil of the cup passes in the tube, and, sucking continually the oil out of the cup, drops it into the joint without interruption.

§ 12. *Of the Fire-Grate.*

The grate in the fire-place is not made of a single piece. It is formed of separate bars (fig. 31), which are placed next to each other at the bottom of the fire-place, where they are supported by their two ends. The advantage of this arrangement is, the facility it affords of replacing them individually by new ones, when they are worn out by the intensity of the fire. Besides, if any accident should happen to the boiler, and make the water run off unexpectedly, thus endangering the engine, one may, by means of a crooked poker, easily turn the bars upside down, and consequently extinguish immediately the fire by letting it fall on the road, with the bars that supported it. It is also thus that every evening the fire-box is emptied, after the engine has finished its work.

§ 13. *Of the places occupied by the different parts.*

We shall complete this description, by showing on the whole engine, as represented in figs. 1 and 2, the places occupied by the different parts of which we have spoken.

A, Part of the boiler containing the fire-box.

BB, Stand for the engine-man and his assistant.

C, Chimney of the engine.

D, Place of the cylinders.

E, First safety-valve, with lever and spring-balance, as will be explained hereafter.

F, Second safety-valve, constructed in the same manner.

G, Glass-tube.

H, Gauge-cocks.

I, End of the eccentric-rod.

J, Horizontal guides for the head of the piston-rod, so as to ensure its motion in the exact direction of the axis of the cylinder.

K, Cross-axle, communicating the motion of the eccentric-rod to the slide-rod, by means of the arms KL′ and K*l*′, which are fixed upon it (see figs. 9 and 10.)

L′, Notch for throwing in gear the eccentric-rod with the cross-axle which works the slide-rods.

MM, Rod by means of which the engineman can raise the eccentric-rod, and throw it out of gear with the cross-axle which works the slides. This is performed by means of the arms *m* and *m*′ connected together. When the engineman pulls the rods MM, he causes the arm *m*′ to raise, and with it the small rod *m*′*o*′, which lifts the eccentric-rod out of gear with the arm KL.

N, Handle by means of which the engineman pulls the rod MM, so as to produce the aforesaid effect.

PP, Handles to move the slides when they are thrown out of gear with the eccentrics. These handles, acting upon the cross-axle Q, move the cross-heads RR which are fixed to it. This motion is communicated by means of the rods SS to the cross-heads *rr*, which act upon the axle working the slides.

T, Handle of the regulator, to open more or less the aperture through which the steam passes from the boiler to the cylinders.

V, Steam-chamber, or reservoir, in which the steam is confined till it can escape through the aperture of the regulator, and penetrate into the cylinders.

U, Man-hole, or aperture, closed by a strong iron plate, and large enough to admit a man into the interior of the boiler, when necessary.

XX, Iron knees, by which the boiler is fixed to the frame of the carriage.

ZZ, Springs resting at *aa* on the chairs of the wheels, by means of vertical pins passing through holes in the frame of the engine. One end of the pin resting on the back of the spring, and the other on the upper side of the chair; the whole weight of the machine is thus supported by the wheels, but through the intermediate action of the springs.

bb, Guides for the chair of the wheel to slide up and down, according as the spring bends more or less under the weight of the engine. The upper part of the chair is scooped out to form a small reservoir for oil. This reservoir, as well as the above-mentioned contains a tube and a syphon-wick, for feeding constantly the oil upon the axle, at its rubbing-point with the axle-box.

c, Flexible tube made of hemp-cloth, but supported within by a spring, and through which the water arrives from the tender to the pump of the engine, when a cock fixed to the tender is opened.

p, Water-pump of the engine, which is constantly set in motion by a connexion with the piston-rod of the corresponding cylinder, but which cannot force any water into the boiler, unless a cock which lets the water come in from the tender be opened. The cock is not marked on the figure.

p′, Handle and rod of the safety-cock of the pump, serving to ascertain whether the water really arrives in the cylinder of the pump. This cock leads without, so that when it is open and the pump has its proper effect, a small jet of water may be seen issuing from it, which shows that the pump works right.

ee, Pad, stuffed with horse-hair and covered with leather, to deaden the shocks the engine may give or receive.

f, Cock, by means of which the water that is sometimes carried from the boiler to the cylinder may be forced out by the effect of the steam.

g, Opening made in the double casing of the fire-box, and closed hy a screw-bolt. In withdrawing this bolt, a cleaning-rod may be introduced into the double-casing; and, by means of a forcing-pump, water may be injected with force, to cleanse out the clay sediment left by the

boiling of the water. This cleaning is usually performed once a-week.

h, (fig. 2.) Moveable plate or door, opening the interior of the chimney compartment, by which the end of the tubes and the boiler, the cylinders, the slides, of the steam-pipes leading from the boiler to the slide-boxes, or from the slide-boxes to the chimney, are visible. This door is opened when it is necessary to regulate the slides, as we shall see hereafter.

ARTICLE II.

OF THE PROPORTIONS OF THE ENGINES.

§ 1. *Of the Dimensions of the parts from which the power of the Engine is derived.*

Such is the construction of the locomotive engines employed on the Railway between Liverpool and Manchester. We have made use for our experiments of no other engines but those. To give a complete idea of them, we have now only to state the dimensions of some of the parts, on which the power of the engine more especially depends, as will be seen further down.

The engines on the Liverpool Railway may be ranked in five different classes, as follows:—

Classes.	Diameter of the cylinder.	Stroke of the piston.	Wheels.	Weight	Effective pressure per sq. in. in the boiler.
	inches.	inches.	ft. in.	tons.	lbs.
1 - -	14	16	4 6	12	50
2 - -	15	16	5	12	50
3 - -	11	16	5	8 to 9	50
4 - -	11	18	5	8 to 9	50

In the fifth class come the first engines used by the company at the opening of the railway; their cylinders are ten inches in diameter, and under; the stroke of the piston, the wheels, and the weight of the engine, vary accordingly. But at present they have nearly ceased to be used on the railway; they scarcely ever undergo any repairs, and none of them will figure in our experiments. We need therefore not enter into any particulars concerning them.

Among the thirty-two engines that have been constructed for the company, and of which thirty are still in their possession, there are

2 of 14 inches, (diameter of the cylinder.)
4 of 12 do.
16 of 11 do. with a sixteen inch stroke.
2 of 11 do. with an eighteen inch stroke.

The eight others are of inferior proportions, and rank in the fifth class which we mentioned above.

They are all at the *effective* pressure of 50 pounds per square inch on the boiler.

In proportion as we shall make use of the engines, we shall state more particularly their names, weight and power.

§ 2. *Of the expression of the power of Locomotive Engines.*

It is by these dimensions that it is customary to express the power of locomotive steam-engines. We shall see in the course of this work, that to render that expression complete, and really sufficient to show the effect of the engine, under all circumstances, two other elements ought still to be added to them, viz. the friction of the engine, and the evaporating power or extent of heating surface of the boiler. However, such as they are, they give a tolerably exact idea of the power of locomotive engines.

As to the mode used for stationary steam-engines, which consists in expressing their power by the effect produced, and comparing it to the work a horse would perform, it is easy to conceive such a mode which is very deficient in all cases, as we shall see, is at all events not applicable to locomotive engines, for the following reasons:—

1. Because the power of a locomotive engine does not depend alone on the force residing in the steam; it depends also on the weight of the engine, which produces a greater or less adhesion of the wheels to the rails, and consequently the locomotion of a more or less considerable load.

2. Because the engine must move at different rates of speed. Now, besides the weight of the load, the engine must also move itself along by overcoming its own friction. That friction, entering therefore as an invariable quantity in the resistance, from which it must always be first of all deducted, it limits, according to each velocity, the final power remaining in the engine as applicable to the load. The con-

sequence of this is, that, if we were to express the power of the engine by the effect produced, we would find that measure different at each degree of speed at which we would consider the engine.

3. Because locomotive engines moving three or four times quicker than horses can do, it would be but an unintelligible fiction to pretend to assimilate them to horses.

§ 3. *Dimensions of the Fire-box and Boiler in twelve of the best Locomotive Engines of the Liverpool and Manchester Railway.*

According to the remark we have made here above, and which will be confirmed in the course of this work, any expression of the power of a locomotive engine becomes imaginary, unless its evaporating power, or the extent of the heating surface of its boiler, be given at the same time. It is, in fact, in the fire-box and boiler that resides the real source of the power of the engine. From thence results all the effect produced. The cylinder and other parts are the means of transmitting and modifying the power; but what could be their effect, if that power itself did not exist?

To complete, therefore, the proportions already given above, we shall add here a table of the dimensions of the fire-box and boiler in the different engines to which we shall have occasion to refer. At a future period, our experiments will enable us to replace this complex expression by the simple expression of the evaporating power of those same engines.

The two most important columns of this table, are those which show the extent of surface exposed to the radiant heat of the fire, and to the communicative heat of the flame.

DIMENSIONS OF THE FIRE BOX AND BOILER OF TWELVE OF THE BEST LOCOMOTIVE ENGINES OF THE LIVERPOOL AND MANCHESTER RAILWAY.

Name and number of the engine.	Diameter of the cylinder.	Length of stroke of the piston.	Diameter of the boiler.	Length of the boiler and tubes.	Number of tubes.	Diameter of the tubes.	Area of the fire-box or surface exposed to the radiating caloric.	Area of the tubes, or surface exposed to the contact of the flame and heated air.	Area of the fire-grate.	Quantity of fuel contained in the firebox to the hgt. of the lowest row of tubes.	Diameter of the chimney.	Remarks.
	inches.	inches.	feet.	feet.		inches.	sq. ft.	sq. ft.	sq. ft.	cub. ft.	inches.	
Samson . . No. 13	14	16	3.50	7	140	$1\frac{5}{8}$	40.20	416.90	7.50	10.87	12.50	This engine is now being reconstructed.
Jupiter . . " 14	11	16	2.75	6.50	79	do.	36.06	226.80	6.08	11.12	12	
Goliath . . " 15	14	16	3.50	7	132	do.	40.31	407	7.50	10.87	12.50	
Vulcan . . " 19	11	16	3	6.50	107	do.	34.45	307.38	6.50	7.64	13.50	
Fury . . . " 21	11	16	3	6.50	107	do.	32.87	307.38	6.12	8.13	13.50	The tubes of this engine are very thin.
Victory . . " 22	11	16	3	6.75	97	do.	37.63	278.53	6.27	11.47	13.50	
Atlas . . . " 23	12	16	3	7.88	65	do.	57.06	217.88	9.20	13.06	12	
Vesta . . . " 24	$11\frac{1}{8}$	16	2.75	7	80	do.	46	256.08	7.06	11.72	1.15 0	
Liver . . . " 26	11	16	3	6.50	97 { 70 / 27	$1\frac{3}{4}$ / $1\frac{3}{8}$	39.66	284.01	8.11	12.48	13.50	
Ajax . . . " 29	11	18	2.75	6.66	63	2	32.64	228.14	6.08	8.32	13.50	
Leeds . . " 30	11	16	3	6.50	107	$1\frac{5}{8}$	34.57	307.38	6.19	8.23	13.50	
Firefly . . " 31	11	18	3	7.50	110	do.	43.91	362.60	7.16	14.30	13.50	The fire-box of this engine is at present being altered.

It will be seen hereafter, that with a boiler of those dimensions and of such a form, the engines are able to evaporate about a cubic foot of water per minute, or a pound of water per second, at the effective pressure in the boiler of 50 lbs. on the square inch.

Comparing with each other the extent of surface exposed in each engine to the action of the heat, a great distinction must be made between the surfaces exposed to the immediate and radiating action of the fire, and those which only receive the heat by communication, during the passage of the hot air from the fire-place to the chimney. An experiment made by Mr. Robert Stephenson is mentioned in Wood's work, p. 403, from which it appears that the two effects stand to each other in a ratio of three to one. Circumstances did not allow us to repeat the experiment.

It was made with a boiler similar to those described above, but the upper part of which had been taken off, and the water exposed to the direct action of the fire, separated from that which receives only the communicative heat; the water was put into ebullition, and, after it had boiled for some time, the water that had been evaporated in each compartment was measured. It was then ascertained that each square foot of surface exposed to the heat of the radiating caloric, had evaporated three times as much water as the same extent of surface exposed to the hot air. This proportion may be considered as sufficieutly established by the experiment, in so far at least as regards a boiling apparatus, similar to those described above.

§ 4. *Of Locomotive Engines of a different construction.*

The description given above is applicable to the most powerful engines constructed until the present time. That form is exclusively adopted on the Liverpool and Manchester Railway.

On other lines, engines of different constructions are to be found. The Railroad from Stockton to Darlington being used for a different service, that is to say, for a more moderate speed, it may be proper to give here an idea of the engines used on that line.

The company possess twenty-three locomotive engines of different models, from the oldest to the most recent ones.

In some of them the fire passes through the boiler in a single tube, which serves as a fire-box, and communicates directly with the chimney. In some others the tube bends round in the boiler before it reaches the other end, and comes back to the chimney, which, in that case, is placed next to the door of the fire-box. In others, the tube or flue, when it reaches the end of the boiler, divides and returns towards the chimney, as two smaller tubes. In some, the fire being still placed in an internal flue, the flame returns to the chimney by means of about 100 small brass tubes, on a principle similar to that of the Liverpool engines. Lastly, three of them are constructed on the same model as those of Liverpool.

The company carries both passengers and goods. The first travel with a speed of twelve miles, and the second of eight miles an hour. Of the different forms of boilers, those only with a set of small tubes suit for carrying passengers; the others cannot generate a sufficient quantity of steam. But when a speed of eight miles per hour only is required, and for an average train of twenty-four wagons, which, in going up the line empty, are equal to a load of about sixty tons on a level ground, the most convenient boilers have been found to be those with one returning tube. They generate a sufficient quantity of steam for the work required of them, and have the advantage of being cheap in regard to prime cost and repairs, as their form is simple, and they are entirety made of iron, whilst the tube boilers require the use of copper.

Besides the difference in the form of the boilers, the other parts of the engine differ also. The cylinders are placed on the outside, and in a vertical position. The motion is not communicated from the piston to the engine by a crank in the axle, but by a rod on the outside of the wheel, resting upon a pin fixed in one of the spokes. Those engines have in general six equal wheels, of four feet diameter each. Two of the wheels are worked by the cylinders, as has been just explained; and the four others are attached to the first by connecting rods, that cause them to act all together.

The weight of these engines varies.

Setting aside the three which we have mentioned as being on the model of the Liverpool ones, and which weigh only about five tons and a half, the average weight of the others is from ten to twelve tons.

All those engines are supported on springs. In some of the older ones, the water of the boiler, pressing upon small moveable pistons, and pressed itself by the steam contained in the boiler, was intended to supersede the springs; but though that system displayed a great deal of ingenuity, the spring it formed was found in practice to be too variable, and the system was given up.

The usual proportions adopted for the engines on that railway are the following:

Cylinder	- -	14½ inches.
Stroke	- -	16 —
Wheels	- -	4 feet.
Weight	- -	11 tons.
Effective pressure	-	48 lbs. per sq. in.

The pressure, however, varies according to the ascertained solidity of the boiler. When the sheets of which it is formed begin to grow very thin, the pressure is sometimes reduced to 36 lbs. only per square inch; in other circumstances, it is, on the contrary, increased to 60 lbs.

CHAPTER II.

OF THE PRESSURE IN STEAM-ENGINES.

ARTICLE I.

OF THE PRESSURE CALCULATED ACCORDING TO THE LEVERS AND THE SPRING-BALANCE.

§ 1. *Of the principle on which that calculation is founded.*

When an elastic fluid is confined in a closed vessel, it produces in every direction on the sides of the vessel a pressure, which is the result of its elastic force, and which gives the exact measure of that force. If, the vessel being already filled with steam, a fresh quantity is continually added, the elastic force of the steam will augment more and more, and consequently also the pressure it produces on every square inch of the surface of the vessel. Now, if at one point of the vessel there be an aperture, closed with a moveable piece supporting a certain weight, it is clear that, as soon as the steam contained in the vessel produces upon the moveable plate a pressure equal to that of the weight which holds it down in the opposite direction, the plate will begin to be lifted up; the passage will then be opened, and the steam escaping through the aperture, will show that its pressure was equal to the weight that loaded the plate or valve.

It must, however, be observed, that the resistance which opposes the egress of the steam does not consist only in the weight that has been placed on the valve. Besides that weight, the atmosphere produces also on the valve a certain pressure, as well as upon every other body with which it comes in contact. That pressure is known to be equal to 14.7 lbs. per square inch. It is therefore the weight, added to the pressure of the atmosphere, that gives the real measure of the elastic force of the steam; while the weight alone represents only the surplus of the pressure over the atmospheric pressure, or what is called the *effective* pressure of the steam. Consequently, when a valve has a surface of five square inches, and supports a weight of 250 lbs., which, divided between the five square inches, gives a resistance of 50 lbs. per inch, that amount of 50 lbs expresses the *effective* pressure of the steam, a valuation frequently made use of on account of its convenience for calculation, whereas, 64.7 lbs. is the real resistance opposed, and therefore the real pressure of the steam.

This is the principle on which are established the means of judging the amount of pressure in locomotive engines. However, as those engines are required to work with at least 50 lbs. effective pressure per square inch, and as, in order to give passage, if necessary, to all the steam generated in the boiler, a valve must not have less than 2½ inches diameter, or 5 square inches surface, it follows of course that if a weight is to be applied directly upon the valve, it must be equal to 250 lbs. Such a weight would afterwards render it very difficult to lift up the valve with the hand, which frequently becomes necessary in the working of the engine, and particularly to ascertain whether the valve may not have contracted an adhesion to its seat which would make it useless.

It was therefore necessary to produce the pressure by means of a lever; for, if

we suppose the lever divided in the proportion of 5 to 1, a weight of 50 lbs. suspended at the end will be sufficient to produce the required pressure without the disadvantage of having a considerable weight to move. But, on the other hand, as, in the rapid motion of the engines, a weight suspended at the end of a lever was found to be continually jerking, and consequently opening and shutting continually the valve, the weight was replaced by a spring, and that is the manner in which the valves are at present constructed.

§ 2. *Of the Levers and Spring-Balance.*

It will easily be conceived that no exact calculation can be established of the power of locomotive engines, without knowing exactly the pressure of steam in the boiler, which is the intenseness of the propelling force of the motion. If we were to depend on the *nominal* pressure of the engine, that is to say, the pressure declared by the constructor, great mistakes might be incurred: for it sometimes happens that, with a view to give to a locomotive engine the appearance of executing more than others, though at the same pressure, its pressure is declared to be 50 lbs. per square inch. whilst it really is 60 or 70 lbs. Moreover, the calculation of the pressure is generally so incorrectly made, that scarcely any dependance can be placed upon it.

We have therefore been obliged to make a particular study of that part of our subject.

We shall first give the manner of ascertaining the pressure by weighing and measuring the different parts of the valve apparatus, in case one should have no mercurial gauge. We shall afterwards show the cause of some mistakes which may be incurred by that mode of calculation, and which are avoided by using the mercurial steam-gauge. Lastly, we shall point out the uncertainty to which also that instrument is liable, and we shall propose another to be used instead of it.

We have said, that, to produce on the valve a great pressure without being encumbered with a considerable weight, a lever is employed. M (fig. 16) being the boiler, and S the valve, C is a fixed point to which is fastened one of the ends of the lever BC. The lever presses at the point A on the valve by means of a pin, and at the point B it supports a weight, or to speak more accurately, it is drawn by a spring equal to a given weight.

The diameter of the valve, the proportions of the lever, and the weight suspended at the point B, or at least the weight represented by the tension of the spring being given, it will be easy to deduce from them the pressure resulting on each square inch of the surface of the valve. And, *vice versa*, it will also be easy to know what weight ought to be applied to the point B, in order to produce at A a given pressure. For, if P represent the weight suspended at B, that weight will produce on A a pressure $P \times \frac{BC}{AC}$ which will consequently be the whole pressure produced on the valve; and if S represent the surface of the valve in inches $\frac{P \times \frac{BC}{AC}}{S}$ will be the pressure produced on each square inch of the surface of the valve.

The levers and valves used by the different constructors of engines vary considerably in their proportions. But, among those proportions there is one, first used by Mr. Edward Bury, of Liverpool, which possesses an uncontested advantage over all other combinations of that sort. It consists in taking for the proportions between the two branches of the lever the ratio of the area of the valve to the unit of surface. By that means the weight P suspended at B gives immediately the pressure produced on the valve per unit of surface. Supposing it should be required to establish a valve of $2\frac{1}{2}$ inches diameter, which make very nearly 5 squre inches surface, and that. in consequence, the ratio between the two branches of the lever has been taken as 5 to 1, that is to say, that $\frac{BC}{AC} = \frac{1}{5}$; P expressing the weight suspended at B, it is clear that the pressure produced at A will be $P \times \frac{BC}{AC} = 5P$. This will, therefore, be the total weight on the valve, and the surface of the valve being 5 square inches, the weight or pressure per inch will be $\frac{5P}{5} = P$. The same would take place if,

having a valve 3 inches in diameter, which gives 7 square inches for the surface, the ratio between the branches of lever were to be taken as 7 to 1.

We have said that, to the weight which ought to be snspended at the end of the lever at B, is substituted the equivalent pressure of a spring. This spring is a spiral, which by being more or less compressed, is able to support in equilibrium, and consequently to represent larger or smaller weights. In other words, it is a spring balance, such as is used for weighing in daily occurrences.

This balance consists of a rod T (fig. 16) which is held in the hand, and to which is fastened a plate with a narrow oblong aperture in it. Behind this plate, and in a cylindrical tube, is a spring, the foot of which rests on the basis L, which is fixed to the plate. At its other end, this same spring is pressed by a moveable transverse bar *mn*. At the bottom of the aparatus is a rod P, to which are fastened the objects that are to be weighed. The prolongation of the bar *mn* projects throngh the aperture of the plate, and is terminated by an index which appears on the outside, and which slides up and down the aperture, in proportion as the spring is more or less compressed. Divisions are engraved along that same aperture. In order to mark them, known weights of 1 lb., 2 lbs. &c., are successively suspended at P, and according as those weights, by pressing on the spring, cause the index to rise, the corresponding divisions are marked. The consequence of this is, that when an object of unknown weight is suspended at P, and makes the index rise to the point marked 10, that is to say, to the same point to which a known weight of 10 lbs. made it rise, we conclude that that object also weighs 10 lbs. This is the sort of balance which is used for measuring the pressure in locomotive engines. We see that, by taking it off from the engine, and suspending known weights to it, the divisions may easily be verified, after the balance is graduated.

When on the engine, the foot P of the balance, where the object to be weighed would be suspended, is fixed in a solid manner to the boiler ; and the rod T, which would be held in the hand in common weighing, is fastened to the end of the lever. This rod passes through an aperture cut through the end of the lever, and is fixed above it by a screw which rests upon the lever. When it is required that this balance shall produce a pressure of 10 lbs., nothing more is necessary than to lower the screw until the spring rises to the point marking 10 pounds, and the same for any other weight.

Vice versa, the steam being in the boiler at an unknown degree of pressure, if we loosen gradually the screw until the steam begins to raise the valve, that is to say, until its pressure stands in equilibrium with the pressure of the spring, the pressure of the steam will be known, for the degree then marked by the index will show the weight which is equal to it.

§ 3. *Of the corrections to be made to the Weight marked by the Spring-balance.*

The mode we have just explained is the one commonly used to calculate the pressure on the valve. However, it will easily be conceived, by the manner in which the spring-balance acts upon the valve, that, to know the pressure which really opposes the egress of the steam, it is not sufficient to read the degree where the index stops, and to calculate the effect produced at the end of the lever, as we have done above. In fact, first, besides the weight represented by the spring, and which would be suspended at the end of the lever, it is clear that the weight of the lever itself causes a certain degree of pressure ; for before the steam is able to raise an ounce of the spring, it must raise the whole weight of the lever. The same takes place in regard to the disk of the valve, which must be raised before the steam can have any action on the balance. 2. When any object is weighed with the hand, that object is suspended at the bottom of the balance, but then the hand supports the upper part, that is to say, the rod, with the spring to which it is fastened ; and that effort is not taken into account, because it does not make a part of the weight. Here, on the contrary, the rod, the screw, and the spring, are an additional weight really suspended at the end of the lever, over and above the pressure marked by the spring ; they must all be raised before the spring can be pressed upon in any way, and can register any

effort; they must therefore be taken into account. The true pressure which takes place on the valve will consequently not be known, until are added to the weight marked in the balance: 1. The pressure produced by the weight of the lever at the place of the valve: 2. The pressure produced at the end of the lever by the weight of the rod and spring of the balance.

1. To know the effect of the lever on the valve, the lever must be unfastened from the balance; a string must be wound round the pin A, or passed through the aperture of the lever at that place, and then, with another spring-balance, the lever must be weighed by means of the string. It is clear that the weight marked by the second balance will be the pressure produced by the lever at the place of the valve; to that must be added the weight of the disk of the valve, which must also be weighed separately, by putting it into the basin of a common pair of scales. When the levers have a total length of 3 feet with the usual thickness, they commonly weigh 27 lbs. or 28 lbs. at the place of the valve. The disk of a valve of $2\frac{1}{2}$ inches diameter, and half an inch thick, weighs in general about 10 ounces. There is therefore a weight of $28\frac{1}{2}$ lbs. to be divided on the whole surface of the valve; so that if that surface is equal to 5 square inches, it makes $5\frac{1}{2}$ lbs. per square inch. When the levers are only 15 inches long, they generally weigh $7\frac{1}{2}$ lbs. at the place of the valve, which makes, together with the disk, 8 lbs. 8 oz., and divided between the 5 square inches, a little more than $1\frac{1}{2}$ lbs. per inch.

2. To know the weight of the part of the balance supported by the lever, the balance ought to be taken to pieces, and the spring with its rod weighed separately. However, this operation may be avoided by taking the balance in one's hand, and suspending it in the contrary direction in which it is placed in the common act of weighing, that is to to say, with the foot above and the rod below; the weight marked by the index will then be equal to the difference between the weight of the rod and spring, and the weight of the foot. If, therefore, the total weight of the balance be known, which is easy, by placing it in the basin of a common pair of scales, the weight of each of its parts may easily be calculated, and consequently also the weight of the rod and spring.

In fact, the degrees having been marked on the balance when in its usual situation, zero was inscribed at the point where the index stood when the spring bore no weight at all, or more exactly when it only bore the weight of the foot. Afterwards fresh weights were successively added, and for each of them the corresponding number was inscribed on the plate, always omitting the weight of the foot, which in fact ought not to be reckoned. The numbers inscribed on the plate represent, consequently, the real tension of the spring, less the weight of the foot of the balance. Now, by turning the balance upside down, the spring is drawn by the weight of the rod and spring which it then bears. If it had borne a weight equal to that of the foot, it would have marked zero; if, therefore, it marks 2 lbs. or 3 lbs., the rod and spring weigh 2 lbs. or 3 lbs. more than the foot.

Supposing thus: B to be the total weight of the balance, T the weight of the rod and spring, and P′ the weight of the foot; if the balance turned upside down shows m weight, we shall have

$$m = T - P';$$

but, on the other hand, the weight of the balance is equal to the weight of its two parts, or

$$B = P' + T:$$

adding therefore together these two equations, we find

$$B + m = 2\,T, \text{ or } T = \frac{B+m}{2}.$$

When the valves have a lever of 15 inches only, the balance used weighs generally 4 lbs., and when turned upside down, it marks $1\frac{1}{2}$ lb.; so in that case the weight, of the rod and spring is

$$T = \frac{4 + 1.5}{2} = 2.75 \text{ lbs.},$$

which is the weight to be added at the end of the lever; that is to say, to the weight already marked by the balance.

When the valve has a lever of 3 feet, the balance requires smaller divisions. It usually weighs only 2 lbs., and turned upside down, marks $1\frac{1}{2}$ lbs., which gives in that case for the weight of the rod and spring

$$T = \frac{2 + 1.5}{2} = 1.75 \text{ lbs.:}$$

adding therefore those weights to those marked by the index of the balance, and taking besides into the account the weight of the lever, as mentioned above, we shall then have the real pressure produced by the whole apparatus on the valve. Dividing it by the area of the valve, the result will be the pressure effected upon each unit of surface.

From this we see that, with a long lever, the error of pressure per square inch may amount to 7 lbs. or 8 lbs., and that, even with a short lever, it may be 3 lbs. or 4 lbs., which is still considerable.

Keeping the preceding notation, that is to say, P being the weight shown by the index, T the weight of the rod and spring, L the weight of the lever, weighed as mentioned above, and D the weight of the disk, lastly BC and AC being the arms of the lever, and S the surface of the valve in square inches, the pressure produced per unit of surface will be

$$\frac{(P + T)\frac{BC}{AC} + L + D}{S}.$$

It is for not having taken these considerations into account that we find so often on locomotive engines spring-balances, which are supposed to be fixed at 50 lbs. pressure per inch, but which are really fixed at 55 lbs. or 60 lbs. We shall soon have frequent occasion to apply and verify these principles, which by that means will be rendered perfectly clear.

§ 4. *Of the Miter of the Valves.*

These are not the only causes from which errors may result. There are two others which are frequently met with in the valuation of the pressure of locomotive engines, and which are not so easy to correct as those we have just mentioned.

In order that the valves may exactly close the opening to which they are applied, without being subject to contract an adhesion with the seat that supports them, it is necessary to make them slightly conical, or at last with a slanting border. When these valves rest upon their seat, which they completely fill, it is very clear that the steam can only act upon their inferior surface; consequently, the area we have here above expressed by S, must be taken after the ***inferior*** diameter of the valve. By calculating in that manner, the exact pressure will indeed be found for every case in which the valve still touched the seat, or, if raised at all, was only so for an instant, or in a very small degree; but whenever the steam, being generated in greater quantity than it is expended by the cylinders, escapes with force through the valve, it raises considerably the disk of the valve; the consequence then is, that, instead of acting on the inferior surface of the valve, it evidently acts on a greater surface, and which is the greater the more the valve is raised. For instance, in fig. 20 it acts on the surface ***cd*** instead of acting on ***ab***. In that case the area S ought to be calculated on ***cd***, and not on ***ab***. But how are we to know ***cd***, unless we calculate it by the rising of the valve, which is a very difficult, if not an impossible, operation? Moreover, the difficulty is complicated by the circumstance that, from ***a*** to ***b*** the pressure of the steam acts directly to raise the valve; but from ***c*** to ***a*** and from ***b*** to ***d*** the action of the steam takes place only in a lateral direction, and according to an angle, which varies in proportion as the valve is more or less raised.

The effect of this alteration in the diameter of the valve, which at first sight appears to be of very small consequence, is in fact very considerable. Let us suppose, for instance, that we have a valve of 2.50 inches diameter at the bottom, and 3 inches at the top, of which we shall find several examples hereafter. Let us further suppose that, by the effect of the blowing of the steam, the valve has been raised so as to have increased its real diameter only by one-eighth of an inch; that is to say, that it is become $2\frac{5}{8}$ inches instead of $2\frac{1}{2}$ inches, or 2.625 inches, instead of 2.50 inches. The surface of the circle being expressed by $\frac{1}{4}\,\pi\,d^2$, where d stands for the diameter and $\pi = 3.1416$, the proportion of the circumference to the diameter, the surface of the valve, which was at first

$$\frac{1}{4} \times 3.1416 \times \overline{2.5}^2 = 4.91 \text{ sq. inches,}$$

has become

$$\frac{1}{4} \times 3.1416 \times \overline{2.625}^2 = 5.41 \text{ square inches.}$$

Consequently, if we suppose the total weight supported by the valve, including

the levers, rod, disk, &c., to be 245 lbs., that weight, when the valve is shut, will represent a pressure per square inch of

$$\frac{245}{4.91} = 50 \text{ lbs.};$$

and when the valve is raised, that same weight will only represent a pressure of

$$\frac{245}{5.41} = 45.27 \text{ lbs.};$$

by which we see that the same weight marked by the balance corresponds to very different pressures of steam, when the valve is shut or when it is raised.

Continuing, in the case of a blowing-valve, to calculate upon what is called the diameter of the valve, that is to say, on its inferior diameter, an error will thus be committed of 5 lbs. pressure per inch, which error might be still greater if the raising of the valve should happen to be more considerable. Moreover, as there is no practical means by which to learn by how much the diameter of the valve is augmented by the raising, the consequence will be that the mode of calculation explained here above, even with the corrections we have made, will apply exactly only to those cases where the valve just begins to be raised, or lets scarcely any steam escape; but the greater the raising the more the calculated amount will surpass the real pressure. We shall see hereafter examples of this.

But still this is not all. If the pressure of the steam in the boiler must be deduced from maasurements taken on the engine, it must also be observed that it frequently happens, in order to make the construction more easy, that the miter of the valve is made to join the sides of its seat only within a certain breadth, as may be seen in fig. 21. The consequence is, that the surface *ab*, or the inferior part of the valve, which has been measured, is not the surface upon which the pressure is divided. The real diameter in this case is *cd*, If therefore there be between *ab* and *cd* a difference, for instance, of one-eighth of an inch, this difference may produce, as well as in the case of the raising of the valve, a difference of 4 to 5 lbs. in the pressure. Mistakes may be avoided in that respect, by measuring not only the inferior diameter of the valve, but also the diameter of its seat. There still, however, remains the blowing of the valve, the exact appreciation of which escapes all manner of calculation.

The mercurial gauge, which we are going to describe, is the means of avoiding both causes of error; but that instrument is expensive, and as yet so scarce, that in all the factories and on all the railways, except the Liverpool one, there is at present no other mode of ascertaining the pressure than those explained above.

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ARTICLE II.

OF THE MERCURIAL STEAM-GAUGE.

§ 1. *Construction and use of the Mercurial Steam-gauge.*

The calculations we have made may be sufficiently exact for a great number of cases. Still they present some degree of complication that makes them inconvenient; besides, they cannot be made without measuring and weighing different parts of the engine, which operations require time and care, and can only take place when the engine is at rest. We may therefore easily conceive the great utility of an instrument which at first sight, and by its bare inspection, will give the exact measure of the pressure of the steam. By means of such an instrument, all cases, even those of the raised valve, present no longer any difficulty, and the nccessity of calculation itself may be dispensed with. The only thing required is, the possibility of submitting the engine to the proof.

The instrument used with that view is, the mercurial steam-gauge, constructed on the same principle as the common barometer. M *bm* (fig. 18) is a tube containing mercury, which ought not to rise above the two points M and *m*. FG is the water reservoir. It must not contain water above the cock E, the use of which is to get rid of the surplus of water that may have been produced by condensation on some former experiment. R is an opening closed by a cock, and through which mercury or water may, when wanted, be introduced into the instrument. Lastly, C is an ajutage on which a tube is screwed, the other end of which reaches the boiler of the engine. This tube is flexible, and usually made of tin; it forms the communication of the mercurial gauge with the engine. At the point where it reaches the engine, it is screwed on an aju-

tage fixed to the boiler, and kept close by a cock.

To prepare the instrument for use, an additional quantity of mercury is poured into it by the aperture R, in order to be sure that the instrument contains mercury at least to the height M*m*. After this the screwbolt M is unscrewed, so that if there happen to be too much mercury it may run off. When this is done the screwbolt is replaced, and an additional quantity of water is also poured through R into the reservoir FG, and, should there be too much, it also runs off through the cock E. Then the instrument is put in communication with the boiler. The steam, arriving through the tube C in the upper part of the reservoir FG, presses on the water by virtue of its elastic force; it consequently presses the mercury down in the branch *mb* which is open at the top, until the weight of the mercury, thus raised, is equal to the pressure of the steam issuing from the boiler. A float borne on the surface of the mercury, at the point *m*, rises in proportion as that surface in the tube; and an index suspended to a thread which passes over a communication-pulley *p*, falls between the two tubes in proportion as the mercury rises in the branch *bm*, and shows upon a graduated scale the variations that occur in the level of the mercury in the different experiments. Supposing the length of the instrument from M to *b* be $6\frac{1}{2}$ feet, or 78 inches, the ascending column may, if necessary, contain 156 inches of mercury; and as a column of 156 inches of mercury with a basis of 1 square inch weighs about 80 lbs., such a column may serve to measure an effective pressure amounting to 80 lbs. per square inch.

The reservoir FG is a cylinder 3 inches in diameter and 6 inches high. The use of the water it contains is to keep the branch M*b* constantly full of water, in proportion as the mercury descends in that branch. This is the reason why that reservoir is a great deal larger than the tube, and its capacity is calculated so as to be able, in case of need, to fill the whole branch. If this precaution were to be omitted, the water formed by condensation in the instrument during the experiment would fall in the tube, which being very narrow, having, for instance, no more than one-half square inch area, the water would immediately rise in it to a considerable height, and cause by that means a surplus of pressure which would make the result false. But by means of the reservoir FG, the condensation-water, in proportion as it is formed, is divided over a surface of 7 square inches, on which, consequently, it produces an imperceptible difference in height. As it is known that the pressure of the water on the unit of surface depends solely on its height, the consequence of this arrangement of the instrument is, that the surplus of pressure caused by the condensed steam is so small, that it may be neglected without any inaccuracy.

To graduate the scale of the instrument, we may begin by marking, first, the point zero. For this, the mercury and the water being poured in, as said above, the two branches must be left to communicate freely with the atmosphere, and the point where the index stops will be the point sought, for that is the position which the float naturally takes when the branch M*b* bears no more than the atmospheric pressure. If the two branches of the bent tube were to contain nothing but mercury, it is clear that the point corresponding to zero in the rising branch would be at *m*, as the mercury would in that case stand on a level in the two branches. Instead of that, the mercury in the branch M supports a certain weight of water, that is to say, the weight of the column EM; it will consequently tend to descend in that branch and to rise in the other. However, if the float is made to weigh as much as the column of water, the level will remain the same as if there were only mercury in both the branches.

The other extreme point of the scale must afterwards be marked. Let ϖ be the pressure we want to equilibrate; supposing the equlibrium established, let x be the height at which, by virtue of that same pressure ϖ, the mercury will stand above its natural level in the branch *m*. The mercury having risen in the branch *m* to the height x, it must have fallen by an equal quantity in the other branch; for the mercury added on the one side can only proceed from what has been taken off on the other. The mercury in the branch M will therefore at the same time be at the point x', and the whole part of that branch from the point x' to the point M will be filled by the water

from the reservoir. If through the point x' we draw an horizontal plane, the mercury which is under that plane will equilibrate itself in two branches; we have therefore nothing to do with it, and need only consider the conditions of equilibrium for those parts which are above the plane in the two branches. Now, we have on the one side the pressure ϖ more the weight of a column of wate rhigh $Mx'=x$; and on the other side, we have a column of mercury high $2x$ more the weight of the atmosphere. P being thew eight of the column of mercury, P′ that of the column of water, and ρ that of the atmosphere, we shall have, there being an equilibrium,

$$\rho + P = P' + \varpi, \text{ or } P = P' + (\varpi - \rho).$$

$(\varpi - \rho)$, which is the surplus of the real pressure of the steam over the atmospheric pressure, is called the *effective* pressure; and all high-pressure steam engines it is this which is to be considered. The column of mercury, the weight of which we have expressed by P, having for its basis the basis of the tube which we shall express by b, and for its height the height $2x$, its volume will be $2bx$; δ representing the density of the mercury, $2\delta bx$ will be the mass of the whole column, and g expressing the accelerating force of gravitation, $2g\delta bx$ will be weight; that is to say, that we shall have

$$P = 2g\delta bx.$$

By the same reason δ' being the density of the water, the weight P′ of the column of water will be expressed by $g\delta' bx$, its basis being also b, and its height $Mx' = x$. But the density of the water being expressed by 1, that of the mercury is expressed by 13.568; thus we have

$$\frac{\delta'}{\delta} = \frac{1}{13.568} \text{ or } \delta' = \frac{\delta}{13.568}.$$

and consequently

$$P' = \frac{g\delta bx}{13.568}.$$

On the other side, the effective pressure $(\varpi - \rho)$, in whatever manner it be expressed, may be replaced by the weight of a column of mercury, that would produce the same pressure on the basis b. If then h be the height of that column, which it is easy to calculate, we shall have

$$\varpi - \rho = g\delta bh;$$

and the equation of equilibrium will thus be

$$2g\delta bx = \frac{g\delta bx}{13.568} + g\delta bh,$$

or

$$x\left(2 - \frac{1}{13.568}\right) = h.$$

This equation gives

$$x = h \times \frac{13.568}{26.136} = h \times 0.51913.$$

The height h of a column of mercury, which may represent a given pressure, is easily found; for we know that a column of mercury, one inch high, presses on its basis at the rate of 0.4948 lb. per square inch. The height of any other column may thus be proportionably calculated. If, for instance, we wish it to represent a pressure of 70 lbs., its height will be found by the following proportion:

$$\begin{matrix}\text{lb.} & \text{in.} & \text{lbs.} & & \text{in.} & \text{in.}\\ 0{\cdot}4948 : & 1 : : & 70 : & h = \frac{70}{0.4948} \times & 1 = & 141.47;\end{matrix}$$

so, that by this value of h, x will be

$x = 141.47$ in. $\times$ $0.51913 = 6$ ft. $1\frac{1}{2}$ in.; that is to say, that to correspond to an effective pressure of 70 lbs., the height of the mercury must be 6 feet $1\frac{1}{2}$ inches.

The same calculation is applicable to any intermediate point that may be sought, but it would be unnecessary trouble; for, knowing the point corresponding to zero, and that which corresponds to the *maximum* pressure of the instrument, we have only to divide the interval into equal parts, and the scale will be suitably graduated, having seen that the general value of x depends solely on the corresponding value of h, and is proportional to it.

This mercurial gauge being once constructed and graduated, whenever any doubt may be entertained in regard to the pressure of an engine, nothing more is necessary than to bring it under the instrument, and by that means the pressure may be ascertained, in whatever state the valve may be at the time, whether blowing or not.

§ 2. *Of the pressure of the Steam in Locomotive Engines while travelling.*

When we make use of the mercurial gauge to discover the pressure during an experiment, attention must be given to a circumstance we are going to describe. If, the valve once regulated, the engine were

to keep an equal pressure of steam during its whole journey, nothing more would be wanting than to try it once for all before starting. Having fixed the valve at the point at which we wish to work, the engine might be brought under the instrument; and the pressure being determined that corresponds to that point, provided no other alteration be made to the spring-balance of the valve, the pressure of the engine for every instant of the journey would be known.

It is thus that many persons calculate, whether or not use has been made of the mercurial gauge. When they have found that an engine lifts up its valve exactly at 50 lbs. effective pressure per square inch, that very moment the valve is considered as giving a free egress to the steam, and it is concluded thence that the steam will never rise above 50 lbs., unless the valve undergoes an alteration. Experience, however, proves that this reasoning is false.

If we observe a locomotive engine with some attention, we shall very soon see that nothing is more variable than the pressure of steam in its boiler, although the valve has undergone no alteration. If the engine runs rapidly with a moderate train, and comes to a slight inclination of the road, however small that inclination may be, it immediately produces a considerable increase of traction, because the gravity of the whole mass on the inclined plane becomes an additional resistance for the engine; and the effect of this increase of traction will be so much the more perceptible on the engine, the less the resistance was which the train offered when on the level parts of the road. It is thus that a load of one ton, which on a level road requires a traction of 8 lbs. only, presents nearly four times as much if it has to ascend an aclivity of $\frac{1}{100}$, the gravity of one ton or 22.40 lbs. on that inclination being $\frac{2240}{100} = 22.40$ lbs. The consequence of that sudden increase of resistance is therefore that the engine, as soon as it arrives at the foot of the inclined plane, must diminish considerably its velocity. Supposing that in its preceding course it spent 480 cylinders of steam per minute, and in consequence of the accidental obstacle it must overcome, it is obliged to reduce its velocity to one-third of what it was before, it will evidently spend no more than 160 cylinders per minute; nevertheless, the fire violently excited by the preceding course will continue to generate the same quantity. That steam, it is true, will be spent at a greater pressure; but experience shows that the surplus of pressure does not balance what is generated too much. The valve will therefore begin to emit an enormous quantity of superfluous steam, which in order to escape will raise the valve; but if we observe that the valve cannot rise without pressing on the spring, and consequently without augmenting the tension of the spring, we will find that the steam can only escape by increasing its pressure; and, in fact, the pressure will immediately rise on the balance several pounds per square inch, in proportion to the violence of the fire and the construction of the engine. How great then is the error committed by continuing to calculate the effective pressure at 50 lbs., because we suppose that the valve giving way at that point cannot suffer the steam to rise above it.

When the steam, in escaping, raises the valve to a given height, the greater the balance-lever is, the more the index will be displaced on the scale, and consequently, the greater will be the increase of tension of the spring; thus, in engines with a long lever, the augmentation of the pressure will be, *cæteris paribus*, more considerable than in those where the lever is shorter.

We shall soon see that the Atlas engine, which has a short lever, with a valve of $2\frac{1}{2}$ inches diameter, is able, while overcoming difficult obstacles, to raise its pressure from 53 lbs. to 56 lbs.; and that the Fury engine, which has a long lever, with a valve of 3 inches in diameter, is able, in the same circumstances, to raise its pressure from 53 lbs. to $62\frac{1}{2}$ lbs. These variations in the pressure depend, in each engine, in the first place, on the augmentation of the resistance created by the obstacle or the diminution of the speed; and, in the second place, on the dimensions of the valves, levers, and balances, and the evaporating power, that is to say, the quantity of steam generated by the engine.

This increase of pressure in locomotive engines, when they meet obstacles that compel them to diminish their velocity, gives the engines with long valve-levers considerable advantage over those with short levers, whenever it is necessary to ascend

an inclined plane. This advantage, it is true, is only gained by submitting the engine to a higher pressure, and might also be acquired with short lever engines by lowering the screw of the spring-balance, so as to increase the pressure in the boiler in the same proportion; but the fact itself would evidently seem the proof of a superior working, and would even be inexplicable, were we to look upon the pressure as never passing 50 lbs.

The variations in the pressure which we have just mentioned, take place while the engine is travelling, that is to say, while it is separated from the mercurial gauge. Therefore, if an engine has been working in a given circumstance, or with a known load, and that we want to ascertain at what pressure it was then working, we must write down exactly, during the experiment, the degrees successively inscribed on the balance; then, when the engine has left off working, we bring it under the mercurial gauge, and by animating the fire sufficiently to make the balance repass through all the same degrees through which it rose during the work, and by observing at the same time the mercurial gauge, we find for each of those degrees the corresponding pressure. That is the means we employed in our experiments.

We brought successively under the instrument all the engines we had made use of, and for each of them, as they all differ in some point from one another, we determined the corresponding degrees of the mercurial gauge with the divisions of the spring-balance.

§ 3. *Experiments on the Pressure of Steam in the Locomotive Engines.*

As those experiments serve to illustrate the foregoing principles, as they give the amount of the effect produced by the miter and the additional parts of the valves, and as they, besides, are the foundation of some of the calculations we shall make on the engines, we shall here give an account of some of them.

I. Atlas; valve $2\frac{1}{2}$ inches in diameter; miter $2\frac{3}{4}$ inches, cut with a slant in the middle of the breadth of the valve, as may be seen in fig. 22; levers 3 inches and 15 inches, or in the proportion of 1 to 5; second safety valve similar to the first, but fixed at too high a pressure to blow in any of the experiments.

The engine being brought to the mercurial gauge on the 15th July, 31st July, and 6th August, 1834, gave the corresponding degrees as follows:

	Degrees of the balance.	Corresponding pressure per square inch, by the mercurial guage.
No. I.	0	4
	10	15.25
	11	15.50
	20	25.50
	20.25	25.75
	20.75	26.25
	22.50	27.50
No. II.	20.25	24.75
	20.50	25.25
	22	25.75
	23	26.25
	23.75	27
	25	28.25
	30	33.50
	30.25	34.50
	30.50	35
	33	37.50
	33.25	38
No. III.	51.25	54
	51.50	54.50
	51.75	55
	52	55
	52.50	55.50

In the first series of those experiments the degrees of the balance were taken with the valve resting on its seat, at least as much as possible, that is to say, the valve emitting scarcely any steam. To obtain this, the engine was brought to the gauge when its work was finished, at the moment when the fire diminishing rapidly, the pressure also decreased continually, so that the blowing at the valve became gradually less, and at last ceased almost compietely. In proportion as the pressure indicated by the mercurial gauge was diminished, the screw of the balance was loosened, in order that it might continue to show the inferior pressures that were produced.

The degree corresponding to zero on the balance, could not be taken exactly; the balance having already fallen a little below zero when the index marked 4 lbs.

In the second series of experiments the engine was, on the contrary, taken at the

moment when the screw of the spring-balance being loosened on purpose, the boiler contained steam at 20 lbs. pressure only. By forceing the fire and tightening by degrees the screw of the balance, the above-marked degrees were produced, and the corresponding numbers of the steam-gauge inscribed. We have seen, that in the first series all the degrees were taken with the valve resting on its seat. Here, on the contrary, the pressure, augmenting rapidly in the boiler, raised continually the valve, so that all the degrees were taken with a blowing-valve. However, as the screw of the balance was tightened in proportion as the pressure increased, the blowing was never very considerable, and scarcely ever showed above 1 or 2 lbs. on the spring-balance.

In the third series, the engine was in its usual working state; that is to say, the spring-balance marking 50 lbs. when the valve was shut by pressing upon the lever with the hand, and the valve rising beyond that point by the blowing of the steam, as far as the force of the steam was able to push it. As the screw was not tightened in proportion as the pressure augmented, the valve in this last case was raised much higher than in the preceding one.

By examining the first series, we see that, in those experiments, the pressure by the mercural gauge is equal to the pressure marked by the spring-balance, with an addition of 5 lbs.

In the second series, we have only 4 lbs. to add to the degrees of the balance.

And in the third series, only 3 lbs.

Those differences are easily explained by referring to the preceding principles.

The valve-lever of this engine, when weighed at the place of the valve, as explained above, gave $7\frac{1}{2}$ lbs.; the disk of the valve weighed $10\frac{1}{4}$ ounces; which makes for those two objects together 8.14 lbs. weight, directly applied on the valve.

Besides, the tolal weight of the balance was 4 lbs., and turned upside down it marked half a pound, which gives for the weight of the rod and spring

$$\frac{4 + 1.5}{2} = 2.75 \text{ lbs.}$$

This weight of 2.75 lbs., acting at the end of the lever, must be multiplied by the length of the lever. So that the whole addition to be made to the tension marked by the spring, is

$2.75 \times 5 = 13.75$, effect of the rod and spring at the end of the lever.

8.14, weight of the lever and disk of the valve.

Sum 21.89

And as the diameter of the valve is $2\frac{1}{2}$ inches, which gives a surface of 4.91 square inches, those 21.89 lbs. divided per unit of surface or square inch, give

$$\frac{21.89}{4.91} = 4.46 \text{ lbs.}$$

So that the real pressure surpasses by 4 or 5 lbs. that which results from the spring of the balance.

This result applies to the valve resting on its seat, that is to say, in taking its diameter at $2\frac{1}{2}$ inches, which gives us for its surface in square inches, and consequently for divisor, 4.91; but as, by the effect of the blowing, the effective area of the valve is augmented, we must not be surprised, if, by a moderate blowing, this addition of 5 lbs. be reduced to 4 lbs., and even to 3 lbs. for a valve that blows violently. If, for instance, the calculation is applied to a pressure of 52 lbs. marked at the balance, we shall have

$(52 \times 2.75) \times 5 = 273.75$ Effect of the weight suspended at the end of the lever, including the rod and spring

8.14 lever and valve.

281.89 total pressure.

Which, divided by 4.91 square inches, gives for each 57.41 lbs.

But in reality the corresponding point of the mercurial gauge is only 55 lbs., the blowing must therefore have augmented the real area of the valve to 5.13 square inches instead of 4.91, that is to say, must have brought its real diameter to 2.55 inches, instead of 2.50 inches.

So it is an addition of $\frac{5}{100}$ of an inch to the diameter of a valve of 2.50 inches, that has been sufficient to produce the difference of $2\frac{1}{2}$ lbs. we observe here. That is the effect of the blowing of the valve, which as we see is considerable; and it can only be known by the mercurial gauge, and not by any measures taken on the engine itself.

II. Vesta; valve $2\frac{1}{2}$ inches diameter; lever 3 inches and 36 inches, or in the pro-

portion of 1 to 12. Second valve of the same diameter as the first, with a lever of $2\frac{1}{2}$ inches and 15 inches, or in the proportion of 1 to 6, marking 50 on the balance, and giving issue to the steam at the same time as the first, but so difficult to move, that 5 lbs. more by the mercurial gauge causes no motion in it. This engine brought to the mercurial steam-gauge on July 28, and August 5, 1834, in the same manner as the *Atlas*, gave the following results:—

	Degrees of the spring-balance. lbs.	Corresponding pressure per square inch, by the mercurial gauge. lbs.
No. I.	8.50	24
	9	24.50
	9.50	26
	10	27
	10.25	28
	10.50	29
	10.75	30
	12	31.50
	12.25	32
	12.50	33
	12.75	34
	13.25	35
	13.50	36
	13.75	37
	14	38
No. II.	20	starting point of the valve.
	21	50
	21.25	51
	21.50	52
	22	53.25
	22.25	54
	22.50	55

The experiments of the first series were made as much as possible with the valve resting on its seat; that is to say, that the screw of the spring-balance was tightened in proportion as the pressure augmented, so that there was scarcely any blowing,

For those of the second series, the engine was brought to the mercurial guage in its usual working state, with the spring-balance at 20, when the lever is pressed upon to shut the valve, and the degrees observed are those that result from the blowing of the steam beyond that point; that is to say, that those degrees are taken with a valve rising from degree 20.

The valve lever of this engine being divided in the proportion of 1 to 12, every weight inscribed on the spring-balance produces on the valve a pressure 12 times as great. The surface of the valve is 4.91 square inches. Multiplying therefore the degrees of the balance by 12, and dividing the produce by 4.91, the pressure resulting from the spring, considered by itself, will be obtained. That calculation is generally considered sufficient.

If the results thus obtained be compared with the corresponding degrees of the mercurial guage in the first series of experiments, it will be found that those results rea always below the real pressure by 3 lbs. or 4 lbs.; this must therefore be the effect of the weight of the additional parts that we are considering.

In fact, the lever of this engine, reduced on purpose by the constructor, weighs 15 lbs. at the place of the valve. The disk of the valve weighs 10 ounces. The balance is not placed in its usual position; it is turned upside down, so that the lever, instead of supporting the rod of the balance, bears only its foot. The weight of this foot is 0.25lb.; for the whole balance weighs 2 lbs., and when suspended with the rod downwards it marks 15 lbs., which is the surplus of the weight of the rod over the weight of the foot; wherefrom results that the weight of the foot is, as has been said, 0.25 lb.

So that the addition owing to these different objects is

	lbs.
Weight of the lever and disk of the valve	15.60
Effect of the foot suspended to the lever 0.25 lb × 12	3.00
Sum . . .	18.60

This additional weight divided over each square inch of the surface of the valve makes 3.8 lbs., so that the calculation in the case of the valve resting on its seat is verified.

As for the cases of a blowing-valve, or those of the second series, the fact shows that the real pressures are less than they would be with a valve resting on its seat by 4 lbs. or 5 lbs., no other means existing of discovering that difference than by the mercurial gauge; so that if we had calculated the pressure in this case in the same way as in those of a valve resting on its seat, that is to say, by dividing the whole weight over a surface of 4.91 inches, or a valve of 2.50 inches diameter, we would have reckoned 4 lbs. too much in each case. It happens here that when the valve is considerably raised, the reduction, owing to the blowing,

compensates at last for the addition required by the weight of the lever, disk, and balance-rod.

These examples prove how faulty would be any calculation of power or effect of engines, the real pressure of which had not been determined by manometrical processes; and it has been already observed, that of all the railways at present in activity, the Manchester and Liverpool Railway is the only one where a mercurial steam-gauge is to be found,

III. FIREFLY; valve 2.50 inches in diameter; miter 3 inches; levers 3 inches and 36 inches. This engine gave on the 2d of August, 1834:

Degrees of the balance	Corresponding pressure per square inch, by the mercurial gauge.
lbs.	lbs.
17 starting point of the valve,	
17	50
20	51

We see that, for this engine, the addition to be made to the pressure marked by the spring-balance is 8.5 lbs. per square inch for lever, disk, and balance; and that in the cases of a blowing-valve, the reduction produced by the miter may amount to 6 lbs., this miter being really considerable.

IV. LEEDS; valve 3 inches; miter 3.125 inches; lever 3 inches and 36 inches; second valve screwed at too high a pressure to let any steam escape during the experiments. The engine gave, on the 28th of July, and 6th of August, 1834:

Degrees of the balance.	Corresponding pressure per square inch, by the mercurial gauge.
lbs.	lbs.
No. I. 28 starting point of the valve.	
29.50	50
29.75	51
30	51.5
30.50	52
31	53
No. II. 31 starting point of the valve.	
32	54
33	55
34	56
36	57.5
No. III. 32 starting point of the valve.	
34	60

V. VULCAN; with valves and levers exactly similar to those of the preceding engine; second valve different, but also fixed too high to give any sign during the experiments: gave on the 28th of July, 1834:

Degrees of the balance.	Corresponding pressure per square inch, by the mercurial gauge.
lbs.	lbs.
31 starting point of the valve.	
35	56.5

VI. FURY; with valves and levers exactly similar to those of the preceding engine; second valve different, but also fixed too high to give issue to the steam during the experiments: gave on the 6th of August, 24th and 25th of July, 1834:

Degrees of the balance.	Coreesponding pressure per square inch, by the mercurial gauge.
lbs.	lbs.
No. I. 31 starting point of the valve.	
33.50	56.50
33.75	57.50
34	58
36	62.50
No. II. 32 starting point of the valve.	
36	67

In the first series of experiments with the LEEDS, the blowing of the valve was from the degree 28 to the degree 31 of the spring-balance. In the second series of the same engine it was from 31 to 36, which is considerable. In the third series it was less, say 32 to 34. It is therefore in that third series that we find the smallest reducing effect of the miter.

The experiment of the VULCAN is the common working state of the engine.

In the experiments of the FURY, there are two different effects of miter as well as in those of the LEEDS.

In consequence of the weight of the levers and balance-rods of these three engines, the addition to be made to the effect of the tension of the spring is 7 lbs. per square inch; but, on the one hand, the blowing, and on the other, the circumstance of the feet of the valve not fitting the valve entirely, produce the reductions we find here. That circumstance explains the anomalies those experiments apparently present.

ARTICLE III.

OF A NEW SPRING-BALANCE AND MANOMETER.

§ 1. *Of a proposed Modification to common Valves.*

All the foregoing calculations are as many

proofs of the difficulty of acquiring a knowledge of the real pressure of the steam by the inspection of the spring-balances, so as they are at present constructed, and the mistakes that must necessarily occur, whenever we have no mercurial gauge at our disposal.

These difficulties might evidently be avoided by adopting a new disposition for the valve, of which, during our stay in Liverpool in the month of July 1834, we left a drawing with one of the directors of the railway company.

The fulcrum of the lever must be placed between the valve and the spring-balance, as in fig. 17, and the balance suspended by its rod as in common weighing; besides, the long branch of the lever must equilibrate round the fulcrum C, with the short branch more the disk of the valve, which can be easily effected by augmenting a little the breadth of the shortest lever, or by putting some additional mass of metal under the valve. Lastly, the proportion between the two branches of the lever must be the same as that of the area of the valve to the unit of surface, and the seat of the valve must be fitted to it exactly.

By means of this simple disposition, it is clear that the degree inscribed on the balance will show immediately, and without any calculation, the effective pressure which takes place in the boiler. In fact, 1. The spring-balance being placed in its usual situation, in which the weight of the foot P is taken into account, no addition will be required for the weight either of the foot or the rod. 2. The two parts of the lever equilibrating with each other, there will be no addition required for the weight of the lever or the valve. Lastly, the branches of the lever, bearing to each other the proportion of the area of the valve to the unit, any number inscribed on the balance will represent an equal pressure on the unit of surface of the valve.

Thus this valve will dispense with all calculation, and will show immediately written on the balance, the real pressure per square inch. It will exactly answer the conditions required of a valve, which is intended only to limit the pressure; that is to say, that if we fix it at 50 we may be certain, without any calculation or consideration whatever, that the steam will raise it precisely at 50 lbs. pressure per square inch. This is all that is commonly required for the business of a railway, where the proprietors only wish, through prudential motives, that the engine may be regulated according to a determined pressure.

In case of theoretical experiments on certain circumstances of the motion of the engines, a deduction must still be made for the effect of the miter in the blowing; inand these cases, recourse must still be had to the mercurial gauge: but we are also going now to propose a portable instrument, capable of being used instead of it; and which, besides, does not require the use of the above-described valve.

§ 2. *Of a new portable Manometer, calculated to replace the Mercurial Gauge.*

We have observed, that at present when we wish to know at what pressure an engine was working in a given circumstance, it is necessary, after the experiment, to bring it to the mercurial gauge, in order to know the pressure that corresponded with the different degrees of the spring-balance, observed during the work.

This second experiment, which must succeed the first, is of itself an inconvenience. Besides it is necessary, in seeking the pressures, to replace all things precisely in the state in which they were during the trial of the engine. In fact, we have seen that a valve fixed at 32 lbs. as starting-point, and blowing at 36, may represent 67 lbs. pressure, whilst that same valve having its starting-point at 31 lbs., the same degree of 36 may only correspond with 62 lbs. The second valve must also have been observed during the work, and be replaced precisely at the same point; for if it be loosened, it will give issue to a certain quantity of steam, which else would necessarily have been forced to escape through the first, and thus have augmented the pressure. Lastly, the engine-men have an interest in concealing the true pressure of the engines, for fear of their being obliged to reduce it. They calculate that it would diminish the speed of their course, and thus keep them longer on the road. In consequence, they not only loosen, secretly, the second valve, and raise from time to time the lever, in order to augment the effect of the miter with which they are very well acquainted, but they also some-

times slip a metal plate, under the pin which presses on the valve, in hopes of deceiving in regard to the real degree of the balance.

The precautions necessary to be taken in seeking the pressure, make that research more fastidious than it would seem at first sight, when one has a mercurial gauge at one's disposal. To this must be added, that the steam necessarily cools in the long passage from the engine to the instrument. It is forced to follow a metallic tube 8 or 10 feet long by half an inch in diameter, and must consequently arrive on the mercury with a less degree of pressure than in the boiler.

These difficulties proceed evidently from the impossibility of fastening the mercurial guage to the engine ; for if that could be done, one might read on it the pressure immediately during the work, and no second experiment would be necessary.

We are therefore of opinion, that that instrument might be advantageously replaced by the following one :—

The engine having its two safety-valves as usual, and constructed in any way, R (fig. 19) is a cock fixed on the boiler, and susceptible, when wanted, of giving issue to the steam it contains. The orifice of the cock bears on the outside the thread of a screw, in order that the instrument may be screwed to it. The upper part of the figure represents the instrument itself. It presents a tube which is to be joined to the ajutage of the cock R. These two pieces being brought next to each other, and bearing each of them the thread of a screw on the outside, a moveable screw E, unites them firmly to each other, as long as the experiment lasts, as may be seen on the figure. Then turning the cock R, the steam will have access into the tube of the instrument.

Besides, A is a valve, the arear of which is one square inch, or any other unit of surface, according to that which one wishes to employ for measuring the pressure. This valve, while tending to rise, acts against a lever AC, the opposite end of which is kept back by the pressure of a spiral spring, forming a common spring-ballance. The two branches of this lever are equal, and their reciprocal weight, including the disk of the valve for the corresponding side, equilibrate exactly round the fulcrum C. Lastly, the point S is fastened by a screw to some part of the boiler, in order to give solidity to the whole.

The instrument being thus fastened to the engine, and the cock opened, the steam will act against the valve, and the consequence of the dispositions we have explained will be, that the inspection of the balance will immediately give the real pressure per square inch. In fact, by the position of the balance, there is no addition to be made for the weight of the rod or foot ; the equilibrium of the lever renders also unnecssary any correction for its weight ; and lastly, the two common valves of the engine giving issue to the surplus of steam, the valve A will never blow. The screw may thus be lowered, until the balance equilibrates exactly the pressure of the steam, by which means no effect of miter will complicate or falsify the result.

The facility with which the real pressure may be found, without being obliged to make purpusely a second experiment ; the accurateness of the observation, the steam not having a long passage to make before it arrives at the instrument ; the advantage the instrument presents of being carried with the engine, and, when necessary, fastened to any other engine ; lastly, its low price, whereas the mercurial steam-guage is very expensive : all those reasons combine to pursuade us that this thermometer may be of some use. With it, all the difficulties we met with in our experiments would immediately have disappeared. It may, besides, also serve to determine the pressure, as well in locomotive engines, as in other high or low-pressure steam-engines.

The accurateness of the instrument may easily be vrified once for all ; 1, by measuring the valve when separated from the engine ; 2, by examining whether the lever equilibrates of itself on the fulcrum ; 3, by taking the balance off and suspending known weights to it, to see whether they coincide with the divisions.

§ 3. *Comparative Table of the different Modes of expressing the Pressure of Steam.*

To complete what has been said in this article, and to facilitate to the reader the converting of the different measures of pressure, which we shall be obliged to make use of in the course of this work, we subjoin here a table of the different modes of expressing the pressure of steam. We

have calculated it by half atmospheres, but the intermediate degrees may be easily filled up.

COMPARATIVE TABLE OF THE DIFFERENT MODES OF EXPRESSING THE PRESSURE OF THE STEAM.

Total Pressure of the Steam.				Surplus of that force over the atmospheric pressure, or effective pressure.			
In atmospheres.	In inches of mercury.	In lbs. per square inch.	In lbs. per square foot	In atmospheres.	In inches of mercury.	In lbs. per square inch.	In lbs. per square foot.
1	30	14.7	2,117	...	...	...	...
1.5	45	22	3,175	0.5	15	7.3	1,058
2	60	29.4	4,234	1	30	14.7	2,117
2.5	75	36.7	5,292	1.5	45	22	3,175
3	90	44.1	6,350	2	60	29.4	4,234
3.5	105	51.4	7,409	2.5	75	36.7	5,292
4	120	58.8	8,467	3	90	44.1	6,350
4.5	135	66.1	9,526	3.5	105	51.4	7,409
5	150	73.5	10,584	4	120	58.8	8,467
5.5	165	80.8	11,642	4.5	135	66.1	9,526
6	180	88.2	12,701	5	150	73.5	10,584

CHAPTER III.

OF THE RESISTANCE OF CARRIAGES MOVED ON RAILWAYS.

§ 1. *Necessity of making further researches on that subject.*

From the description we have given of the engine, we see that the steam, by acting on the pistons, communicates to the wheels a rotary motion, which must necessarily make the engine advance, provided the train that follows, does not oppose a greater resistance than the force of which the engine disposes.

The first point therefore which must be considered concerning the motion of locomotive engines is the resistance opposed by the trains they draw.

Those trains consist of a more or less considerable number of carriages called wagons, upon which the goods are loaded. Their resistance to the motion depends not only on their weight, but also on the state of the railway, and the more or less perfect construction of the carriages. The purpose of the establishment of a railway being to produce a perfectly hard and smooth road, on which the carriages may roll with ease, if the railway is not kept in good order, or if it does not answer the intentions for which it was established, it is clear that the rasistance the train will oppose along those rails will be so much the greater. The same will also take place if the carriages, being ill-constructed or badly repaired, have a considerable friction.

From this observation, we see that the power required to draw a given weight, a ton for instance, cannot be the same upon all railways, nor with all sorts of carriages. On perfectly smooth rails, and with a well-greased and well-constructed wagon, the draft of a ton may require only a power of 8 lbs. We mean to say that a weight of 8 lbs. suspended at the end of a rope passing over a pulley, will, in that case, be sufficient to make a loaded carriage, weighing a ton, move forward. On another railway, on the contrary, and with carriages of another construction, the same load of a ton may require a power of 10 lbs., and perhaps more.

The old wagons, on which some experiments had been made, required a power of 10 lbs. to 12 lbs. for each ton weight of the load. Since that time, the carriages had been brought to greater perfection, and had never been submitted to any experiment made on a large scale, and in the usual working state. At the time of the introduction of the new wagons at Liverpool, one trial had been made with a single wagon, and just at the moment it was coming out of the hands of the maker. But as that wagon had been carefully oiled on purpose for the experiment, and as it had not yet encountered any shock by which the

axles might have been bent, the wheels warped, or the hind wheels prevented from following exactly in the track of the fore ones; and as, moreover, the rails had been nicely swept, the result of such an experiment could scarcely be considered as a common practical result; and, in fact, the friction of the trains continued to be calculated on the Liverpool Railway at the rate of 10 lbs. per ton. These uncertain data could not be admitted in a new work on the subject.

It became therefore necessary for us to find another base for the calculations that were to be made on modern wagons. However, the occasion which gave rise to the experiments we are going to relate, occurred in the work of the locomotive engines. They pointed out themselves, in a way, the errors committed in the appreciation of the resistances they overcame. This point is worthy of notice, as it proves at the same time both the perfection of the engines, and the correctness of the calculations, to which it is possible to submit them. It inspires consequently more confidence in the other results which were obtained in the same way, and it is for that reason we mention it. Having made, during our stay at Liverpool, in 1834, a great number of experiments on the power of locomotive engines, we found than one of those experiments, made with the ATLAS, and which we shall have occasion to relate hereafter, appeared to exceed the limits of the power of that engine. The ATLAS had, on July 23, on an inclined plane at $\frac{1}{1300}$, drawn 40 wagons, weighing 190 tons, and the diameter of its cylinder was only 12 inches. According to the ideas admitted on the railway, on the resistance of the trains, this fact could only be explained, by supposing either that the proportions of the engine were not exactly what they were thought to be, or that the railway had a different inclination from what was computed, or the train a different weight from that inscribed on the weighing books. Other experiments, however, made by us with other engines, in other circumstances, and in other points of the railway, having given similar results, we were already convinced that the friction of the wagons could not exceed 8 lbs. per ton, and that the mistake lay there, unless we preferred supposing that mistakes had been made in the dimensions of all the engines, and in the levelling of all the parts of the road.

It became, therefore, necessary to ascertain the fact in a direct manner, by establishing a series of experiments for that purpose; but it was particularly satisfactory to have been led to the knowledge of the truth by the calculation, as the experiment became thus the verification of it.

§ 2. *Of the Friction determined by the Dynamometer.*

The most natural means of determining the friction or resistance of the wagons, seemed to be the dynamometer, which gives directly the force of traction required to execute the motion; but as the act of drawing, either by men or any other living moter, takes place by starts, the dynamometer oscillates between very distant limits, and can give no certain result. It appeared, however, to us, that if the draft were effected by an engine, the effort of which is always equal, and the motion regulated by the mass of the train itself the oscillation of the dynamometer would not be so great, particularly if the instrument were to be fastened to one of the last carriages, on which the pulsations of the engine have naturally much less effect.

Therefore, at the moment the LEEDS engine was setting off with a train of 12 wagons, after the whole mass had been put in motion, and while the motion continued with an uniform velocity of three or four miles an hour, the chain of the three last carriages was unhooked, and replaced by a circular spring-balance, which had been prepared for the purpose. The rod of the balance was fixed to the frame of the ninth wagon, and the three following, which were the last of the train, were fastened to the spring. The experiment took place between the milestones one and a half and two of the Liverpool Railway, on a space of ground which is a dead level.

We expected to see the index of the balance remain nearly steady; but we were disappointed. Its average position was near the point marking 100 lbs.; but it underwent very great variations, that is to say, from 50 lbs. at least, to 170 lbs. at most; and even two or three times, at certain extraordinary starts of the engine, the needle ran to the end of the balance, marking 220 lbs. As, however, this case happened only

accidentally, it could not be considered as an effect of the regular draft: and, indeed, after the shock which had caused this extraordinary excursion, the needle immediately returned to its usual point of 100 lbs., and began again its oscillation between 50 lbs. and 170 lbs. After having, to no purpose, waited to see whether the motion would become more regular, we concluded that the experiment was not suspectible of a greater degree of precision.

The variations of the needle between 50 lbs. and 170 lbs., gives an average of 110 lbs.

The three wagons weighed together 14.27 tons. So the experiment gave $\frac{110}{14.27}$ or 7.70 lbs. resistance per ton.

It is important to remark, for what will be said hereafter, that this experiment was free from the direct resistance of the air; for these three waggons, being the last of the train, underwent from the air only a very inconsiderable lateral resistance, particularly as the speed was only three or four miles an hour. All the direct resistance of the atmosphore took place on the first carriage of the train, with which our experiment had nothing to do.

This approximation, as it was, might be be useful, but it was thought necessary to obtain more positive results.

In consequence a convenient place having been chosen on the Liverpool Railway, at the foot of Sutton inclined plane, and at a distance of $11\frac{1}{2}$ miles from Liverpool, the level was taken in the most accurate manner, to a tenth of an inch, and the experiments commenced on the following principle:—

§ 3. *Of the Friction determined by the Angle of Friction.*

Let us suppose a heavy body left to itself on an inclined plane AB (fig. 23.) and sliding without friction to the foot of the plane; let us suppose at that point another plane, being the continuation of the first, and on which the same body continues its motion.

The body will descend along the plane, by virtue of its gravity; but that force will act only partially: it will be decomposed into two others, one perpendicular to the plane, which will be destroyed by the resistance of that plane, and the other in the sense of the plane, which will have its full effect, and will be the accelerating force of the motion. If therefore g express the intensity of gravity, and θ' the angle of the plane, with a vertical line, the accelerating force of the motion will be

$$\varphi = g \cos \theta';$$

but the general expression of any accelerating force is $\varphi = \frac{\dot{v}}{t}$, v being the velocity and t the time; consequently

$$g \cos \theta' = \frac{\dot{v}}{t}.$$

Besides, when we consider only an infinitely small interval of time, any motion may be regarded as uniform, which, by expressing by x the space passed over, gives

$$v = \frac{\dot{x}}{\dot{t}},$$

or

$$t = \frac{\dot{x}}{v}.$$

Thus the equation above becomes

$$v\dot{v} = g \cos \theta' \dot{x}.$$

Making the integral, and observing that the velocity is zero at the starting point, or that $x = 0$ gives $v = 0$, we have

$$\frac{v^2}{2} = g \cos \theta' x.$$

This equation gives the velocity of the moving body in any point whatever of the first plane.

Consequently, if we express by x' the distance of the point B, from the starting point, measured along the plane, the velocity of the falling body, when arrived at that point, is

$$V^2 = 2g \cos \theta' x',$$

This is the velocity the body has acquired, at the moment it is going to pass from the first to the second plane. This velocity being applied to it in the direction of the first plane, would produce, in the direction of the second, only a certain velocity, resulting from the relative inclination of the two planes, if the passage from the one to the other took place abruptly. But if the passage is effected by a continued curve, we know that there will be no loss of velocity, and the body will begin its motion on the second plane with the same velocity it had in leaving the first. This will, there-

fore, be its velocity in beginning its descent on the second plane.

The body will, besides, continue to be impelled by gravity. θ'' being the angle of inclination of the second plane with a vertical line, the gravity will produce an accelerating force

$$\varphi = g \cos \theta'';$$

and by a calculation similar to the former, we will also have on that plane,

$$v^2 = 2g \cos \theta'' x + C.$$

In this equation, C is determined by the condition that $x = 0$ must give for v the incipient velocity of the second motion; and as we have seen that this incipient velocity is

$$V^2 = 2g \cos \theta' x',$$

it follows that

$$C = 2g \cos \theta' x'.$$

Substituting that value of C, the velocity in any given point of the second plane is expressed by

$$v^2 = 2g \cos \theta'' x + 2g \cos \theta' x'.$$

Further z' and z'' being the vertical heights gone through on each plane by the moving body, we have

$$x' \cos \theta' = z', \text{ and } x \cos \theta'' = z''.$$

Consequently the equation may be written in the following form:

$$v^2 = 2g (z' + z'');$$

or

$$v^2 = 2gz,$$

by letting z express the vertical height of the point where the moving body is below the starting point.

This is therefore the equation of the motion, in the case of a body moving without any friction or resistance whatever. In that equation we see that we can only have $v = 0$, when $z = 0$; that is to say, that the body once put in motion, will not stop until it has re-ascended the second plane to the height of its starting point, that second plane being then supposed to be inclined in an opposite sense to the first.

But if the body moves with the friction, experience having proved that friction does not increase with the velocity, it will act as an uniformly retarding force, contrary to the gravity along the plane. By the introduction of that new force, the accelerating forces of the motion on each of the planes will no longer be

$$g \cos \theta', \text{ and } g \cos \theta'';$$

but

$$g \cos \theta' - f, \text{ and } g \cos \theta'' - f,$$

f being the expression of the retarding force owing to the friction.

In that case the velocity in any given point m of the second plane, the distance of which to the point B is expressed by x, will consequently be

$$v^2 = 2(g \cos \theta'' - f) x + 2(g \cos \theta' - f) x.'$$

Effecting the indicated operations, and substituting z'' for $x \cos \theta''$, z' for $x' \cos \theta'$ and z for $z' + z''$, we have

$$v^2 = 2 [gz - f(x' + x)];$$

which equation gives the velocity in any point of the motion of the planes, taking the friction in consideration. In that case we see by the equation that we cannot have $v = 0$, unless $z = 0$, $x' = 0$, $x = 0$, that is to say at the beginning at the motion; or unless we have the equation

$$gz - f(x' + x) = 0.$$

If, therefore, a body once put in motion stops at any point, m for example, that point must fulfil the above condition, or we must have

$$gz = f(x' - x).$$

If we multiply the two members of that equation by M, mass of the moving body, we shall have

$$gMz = fM(x + x').$$

The quantity g being the action of the gravity on one of the elements of the body, gM is its action on the whole of that body, or its weight which we shall express by P. Also f is the retarding action of the friction, as relates to a single element of the moving body. But the friction being proportional to the weight, fM is the friction when we consider the whole mass of the body. Expressing, then, that friction by F, and making those two substitutions, the equation may be written in the following form:

$$Pz = F(x + x').$$

Let us suppose, then, that, having left in the beginning the moving body free on the inclined planes, it has descended to the point m, for instance, and has not gone farther; that point must necessarily fulfil the above condition, else the moving body would not have stopped there. If, therefore we measure on the spot the quantities z, x and x', and know the weight P, the equation will contain no other unknown quantity but F; so that equation will give us its value, viz.

$$F = P\frac{z}{x+x'}.$$

Consequently, when a body of a given weight P, placed in the above stated circumsances, stops in descending at a certain point m, ***the value of the friction that stopped it, will be found by dividing the total height from which the body descended by the total distance which it travelled over.***

This determination once made, it is clear that if we were to construct an inclined plane, the height of which were z, and the length $x+x'$, and if we were to place the body on it, it would remain in equilibrium. In fact, the gravity that tends to impel the body onwards would be exactly equal to the friction that retains it.

The ratio $\frac{z}{x \times x'}$ gives us, consequently, what is called the angle of friction; and it is for that reason that we have also called by that name the principle we have explained, and which we shall make use of in the following experiments.

§ 4. *Experiments on the Friction of Wagons.*

A series of experiments was according ly undertaken on that principle, upon one of the inclined planes of the Liverpool and Manchester Railway.

From a point taken on Sutton inclined plane, at 50 chains from the foot of that plane, 34 distances of 10 chains or 330 feet each were measured. At each of these points a numbered pole was fixed in the ground, and the level exactly taken. The following table shows the result of the levelling operation expressed in feet and decimals of feet.

Number of the posts.	Distance from the first post in feet.	Vertical descent below the first post in feet, and decimals of feet.	
0	0	0	Starting point.
1	330	3.47	
2	660	7.07	
3	990	10.62	
4	1,320	14.36	
5	1,650	18.17	
6	1,980	21.77	
7	2,310	25.53	
8	2,640	28.98	
9	2,970	32.07	
10	3,300	34.61	Foot of the inclined plane, or rather middle ponit of the continued curve.
11	3,630	35.06	
12	3,960	35.19	
13	4,290	35.23	
14	4,620	35 37	
15	4,950	35.71	
16	5,280	36.17	
17	5,610	36.44	
18	5,940	36.66	
19	6,270	36.80	
20	6,600	36.92	
21	6,930	37.06	
22	7,260	37.14	
23	7,590	37.22	
24	7,920	37.37	
25	8,250	37.34	
26	8,580	37.63	
27	8,910	37.92	
28	92,40	38.14	
29	9,570	38.35	
30	9,900	38.54	
31	10,230	38.67	
33	10,560	38.77	
33	10,890	38.92	
34	11,220	39.08	

On the ground where the experiments took place, a little beyond the foot of the inclined plane, the wagons had to cross three junction roads, each of them necessitating the passing over three switches, as may be seen in fig. 24. This made in all nine switches, either on one side of the rails or the other. On passing each of these obstacles, the wagon received a jolt from the unevenness of the road, and their velocity was checked. The ground was consequently unfavourable for experiments, and made the friction appear rather more considerable than it really was.

The wagons used for the experiments are of the following construction. They consist of a simple platform, supported on four springs. Their wheels are three feet in diameter, and fastened to the axletree which turns with them. The body of the carriage rests upon the axletrees, but outside the wheels; that is to say, that the axles are prolonged through the nave, in order to support the carriage. At the bearing they are turned down to $1\frac{3}{4}$ inches in diameter. The chair is made of brass at the bearing-point. In its upper part it contains grease, continually feeding upon the axle through a hole in the chair, and the waste of which is prevented by a cover on the underside of the chair. The grease-box, which is filled every morning, is sufficient for the whole day. In the experiments, no alteration whatever was made to the usual disposition; every thing was left as it is in the daily work, as well in regard to the wagons as to the rails. Among the wagons there are some, the extremity of the axle of which, instead of being from one end to the other of an uniform diameter of $1\frac{3}{4}$ inches, is thickened near the frame of the carriage by three eighths of an inch, and is on the contrary diminished as much at the other end. Consequently, that part of the axle is composed of three cylindrical parts equal in length, and the diameters of which are, $2\frac{1}{8}$, $1\frac{3}{4}$, and $1\frac{3}{8}$ inches.

This disposition is adopted, in order to leave the mean diameter as it was at first, but to give, however, a greater strength to the point which appears to suffer the most. There are, nevertheless, but few axletrees constructed on that principle, they having been only meant as a trial, the advantage of which has not yet been confirmed by experience.

I. On July 29, 1834, five wagons taken at random, and loaded with bricks, were brought to the spot fixed for the experiments by the Sun engine. The train was followed by a sixth empty wagon. The weight of five wagons together, accurately taken with their load, amounted to 30.65t, and including the weight of ten persons, not weighed with them, to 31.31t., or to 6.26t. per carriage.

The middle of the train having been carefully placed facing the starting point on the plane, and the engine being taken away, the brakes were taken off all at once, at a given signal, and the five wagons were left to their gravity on the plane. They continued their motion till 33 ft., beyond post No. 30, having thus run a total distance of 9933 feet, with a difference of level, between the points of departure and arrival, of 38.55 feet.

By recurring to the principle laid down above, we had, in this experiment, $x+x=$ 9933 feet, $x=38.55$ feet and the friction was the $\frac{38.55}{99.33}$ or $\frac{1}{258}$ of the weight. Consequently, the friction of a ton was $\frac{1\text{t.}}{258}=\frac{2240\text{ lbs.}}{258}=8.69$ lbs. This friction, however, included the resistance of the air, and was augmented by the above-mentioned circumstance, of the passage of nine switches at the foot of the plane.

II. After this first experiment, 300 bricks were taken out of each of the wagons. The weight of 100 of those bricks having been carefully taken, and found to be 855 lbs.; this was, consequently, an alleviation of 2,565 lbs. or 1.145t. for each carriage. The weight of the five loaded wagons, including the same 10 persons, amounted thus to 25.58t. or 5.12t. for the average weight of each of them.

In this state the wagons were brought back to the same starting point as at first, and left again to their gravity on the plane. They continued their motion until 84 feet beyond the post No. 28, having gone through a total distance of 9324 ft. on a difference of level of 38.19ft. In this second experiment the friction was $\frac{1}{244}$ of the weight, or 9.17 lbs. per ton: so the resistance per ton was less in the first case than in the second.

The wagons were then, for the third time brought back to the starting point,

and each of them was successively and separately left to itself on the plane, as also the empty wagon, when they gave the following results :—

	Number of the wagon.	Weight loaded.	Distance gone through.	Difference of level.	Friction.	Friction per ton.
		tons.	feet.	feet.		lbs.
III.	No. 294	4.65	7,326	37.16	$\frac{1}{197}$	11.36
IV.	100	5.15	6,663	36.95	$\frac{1}{180}$	12.42
V.	196	5.20	7,455	37.19	$\frac{1}{200}$	11.17
	111	5.00	stopped by mistake		"	"
	150	4.85	stopped by mistake		"	"
VI. empty wagon,	202	1.85	6,204	36.78	$\frac{1}{169}$	13.28

The wagon, No. 100, at the moment it arrived, had one of its axle-boxes very hot, which explains why it did not continue its motion as far as the others, though equally loaded. The empty wagon was very low, being formed only of a platform surrounded by an open railing.

According to these experiments, each of the loaded wagons, taken separately, had an average friction of 11.3 lbs. per ton ; and those same five wagons, united together in a train, had only a friction of 9.17 lbs. per ton. The difference in favor of a greater number of carriages was evidently owing to the resistence of the air, the effect of which only takes place on the first carriage. If the train is composed of only one wagon, that one must bear alone the whole resistance ; but if it is composed of several, the resistance of the air remaining the same, is divided between all the wagons, and becomes consequently less peecestible on each of them. The same effect may be observed in the first experiment compared with the second. The number of carriages was the same in both, but the first train being more heavy, the resistance of air was distributed between a greater aumber of tons.

It appeared therefore necessary, in order complete our investigation, to make other experiments, with trains of different weights and in different circumstances. In the following experiments the wagons were no longer loaded with bricks, but with goods of different sorts, such as were furnished by the trade in the common business of the railway.

VII. The following day, July 30, a train of 19 loaded wagons was brought to the same place by the MARS engine. The 19 wagons weighed together exactly 92 tons, giving 4.84 tons for the average weight of each of them. The train was again stopped on the plane, so as to make the middle or centre of gravity of the mass exactly facing the post No. 0 ; and the whole was left to its gravity as in the foregoing experiment. The mass being put in motion, stopped at 168 ft. beyond the post No. 32. So the space gone through was 10,728 ft., and the difference in level between the starting and stopping points was 38.85 ft., which made the friction equal to $\frac{1}{276}$ of the weight, or 8.11 lbs. per ton.

VIII. The same day the same experiment was made with the tender of the JUPITER engine, which stopped at 27 feet beyond the post No. 18, and its friction was, consequently, including the resistance of the air, $\frac{1}{263}$, or 13.76 lbs. per ton. This tender is nothing but a wagon of a particular form, giving, comparatively, a considerable hold to the air, particularly when it is not much loaded. The tender of the JUPITER was then nearly empty, having only sufficient provisions to bring back to Liverpool the persons that were present at the experiment.

This as well as the preceding day's experiments were made jointly with Mr. H. Earle, one of the directors of the railway ; Mr. J. Locke, engineer of the Grand Junction Railway ; Mr. King, of the Liverpool Gas-works, and other persons more or less

directly connected with the administration of the Company.

IX. On the 31st of July the tender of the ATLAS engine, then weighing $5\frac{1}{2}$ t., was left to itself from a point situated at 84 ft. below the post No. 1. It stopped at 90 ft. beyond the post No. 23, having run over a space of 7,266 ft. by 32.88 ft. descent, which gives for the friction $\frac{1}{221}$, or 10.13 lbs. per ton.

X. The same day the train led by the same ATLAS engine, composed of 14 wagons, weighing together 61.35 t., was left to its gravity on the plane from a point situated at 24 ft. above the post No. 1. Not having at our disposal a sufficient number of men, the train could not be stopped before. It ran to 15 ft. before the post No. 5|; that is to say, over a space of 9579 ft., in a descent of 35.32 feet, which gives for the friction $\frac{1}{271}$, 8.26 lbs. per ton.

XI. On the 1st of August a train of 10 wagons was brought to the place of the experiments by the VESTA engine. The 10 wagons weighed together 43.72 t. The tender of the engine, weighing 5 tons, was left attached to them, making thus together 48.72 t. for 11 carriages, or 4.43 t. per carriage. The whole was left to its gravity on the plane, and ran till 108 ft. beyond the post No. 30, being a space of 10,008 ft. on a slope of 38.58 ft. which gives for the friction $\frac{1}{259}$, or 8.64 lbs. per ton.

XII. The same day 24 wagons were brought to the same place by the ATLAS engine, these 24 wagons weighing together 104.50 t., and making with the tender of the engine, which weighed 5.50 t., 110 t. for 25 carriages, or 4.40 t. per carriage. They were left to their gravity on the plane, and did not stop until they reached 108 feet beyond the post No. 32. They ran, consequently, over a space of 10,668 ft., with a descent of 38.82 ft., which puts the friction at $\frac{1}{274}$, or 8.15 lbs. per ton.

Lastly, complete trains, that is to say, the engine, tender, and wagons together, were brought to the trial of gravity on the plane, and gave the following results :—

XIII. On the 2nd of August the FURY engine, followed by its tender and by 17 wagons, weighing as follows : wagons 81.26 t., engine 8.20 t., tender 5.5 t., together 94.96 t., was left to its gravity on the plane. The engine and its tender being, on account of their weight, reckoned for three wagons in the position of the centre of gravity of the mass, the whole was considered as equal to 20 wagons. The train was consequently stopped so as to place facing the starting-post, the interval between the seventh and eighth wagon. The mass, being put in motion, stopped at 42 ft. beyond the post No. 34. It had run over 11,262 feet, with a descent of 39.10 ft. ; which put the friction at $\frac{1}{288}$ of the weight, or 7.78 lbs. per ton, including the engine, tender, and wagons.

The whole weight of the train, engine included, was 94.16 t. The resistance of the whole, taken at the rate of 7.78 t. as it had been found, was then 733 lbs. But the engine, submitted alone and a moment before to the experiment, had been found to have 113 lbs. friction, as we shall see below. Of these 733 lbs. there were, consequently, only 620 applicable to the wagons and tender. Their aggregate weight was 85.96 t. ; consequently, the resistance belonging to them was 7.21 lbs. per ton.

XIV. On the 2nd of August the VULCAN engine, weighing 8.54 t., followed by a train of twenty wagons, weighing 96.30 t., and by a tender weighing 5.5 t., forming together a mass of 110.14 t., was brought to the place of the experiments. Not having been able to stop the train in time, it could only depart from a point situated at 18 ft. below the common starting-post, the engine and its tender being reckoned together for three wagons, in fixing the situation of the centre of gravity. The mass stopped at 39 ft. beyond the post No. 33. The distance ran over in 12′ 10″ was 10,911 ft., on a descent of 38.75 ft. The friction calculated over the whole was consequently $\frac{1}{282}$ of the weight, or 7.96 lbs. per ton.

The total resistance for the 108.50 t. weight of the whole train, engine included, was 863 lbs. ; if from that we deduct 127 lbs. for the resistance of the engine itself, according to an experiment made immediately afterwards, and of which we shall speak below, here remains for the 100.16 t. of the train and tender 736 lbs., which make 7.35 lbs. per ton.

XV. To conclude, on August 15, the LEEDS engine, weighing 7.07 t., followed by its tender and a train of seven wagons, the aggregate weight of which, besides the

engine, was 33.52 t., was also submitted to the same experiment. Starting exactly from the post No. 0, it ran till 255 ft. beyond the post No. 24. Distance 8,175 feet; descent 37.35 ft.; friction of the whole $\frac{1}{219}$, or 10.23 lbs. per ton.

The whole train weighing 40.59 t., had therefore a total resistance of 415 lbs.; and as the engine submitted alone to the experiment had been found to have 112 lbs. friction, on those 415 lbs. there were only 303 lbs. applicable to the wagons and tender, and consequently the resistance belonging to the train was $\frac{1}{248}$, or 9.04 lbs. per ton.

§ 5. *Table of the Results obtained in those Experiments on the Friction of Wagons.*

Bringing together the different experit ments described hereabove, we make outhe following table :—

EXPERIMENTS ON THE FRICTION OF WAGONS.

Number of the experiment.	Date of the experiment.	Description of the trains.	Weight of the train.	Weight per wagon.	Distance run over.	Duration of the race.	Difference of level.	Friction.	Friction per ton.	Observations.
	1834.		tons.	tons.	feet.		feet.		lbs.	
VI - -	July 29	1 empty wagon - - -	- -	1.85	6204	- -	36.78	$\frac{1}{169}$	13.28	This wagon has only a platform surrounded by an open railing.
VIII -	July 30	1 tender - - - - - - -	- -	4.50	5967	- -	26.66	$\frac{1}{183}$	13.76	This form gives a great hold to the air.
III - -	July 29	1 loaded wagon - - -	- -	4.65	7326	- -	37.16	$\frac{1}{197}$	11.36	
IV - -	July 29	1 loaded wagon - - -	- -	5.15	6663	- -	36.95	$\frac{1}{180}$	12.42	An axle-box very hot on arriving.
V - -	July 29	1 loaded wagon - - -	- -	5.20	7455	- -	37.19	$\frac{1}{200}$	11.17	
IX - -	July 31	1 tender - - - - - - -	- -	5.50	7266	- -	32.88	$\frac{1}{221}$	10.13	
II - -	July 29	5 loaded wagons - .	25.58	5.12	9324	10′.20″	38.19	$\frac{1}{244}$	9.17	
I - -	July 29	5 loaded wagons - -	31.31	6.26	9933	10.00	38.55	$\frac{1}{258}$	8.69	
XI - -	Aug. 1	10 loaded wagons and 1 tender (11 carriages)	48.72	4.43	10008	11.45	38.58	$\frac{1}{259}$	8.64	
X - -	July 31	14 loaded wagons - -	61.65	4.40	9579	- -	35.32	$\frac{1}{271}$	8.26	
VII - -	July 30	19 loaded wagons - -	92.00	4.84	10728	11.00	38.85	$\frac{1}{276}$	8.11	
XII - -	Aug. 1	24 loaded wagons and 1 tender (25 carriages)	110.00	4.40	10668	- -	38.82	$\frac{1}{275}$	8.15	
XV - -	Aug. 15	7 wagons 1 tender and 1 engine in front	40.59	4.00	8175	8.30	37.35	$\frac{1}{219}$	10.23	Including the friction of the engine.
XIII -	Aug. 2	17 wagons 1 tender and 1 engine - - - - - -	94.96	4.78	11262	- -	39.10	$\frac{1}{288}$	7.78	
XIV -	Aug. 2	20 wagons 1 tender and 1 engine - - - - - -	110.14	4.83	10911	12.10	38.75	$\frac{1}{282}$	7.96	

During all those experiments the weather was fair and calm. As we have said before, no particular precautions had been taken, nor had anything been altered in the usual state of the wagons or rails. The circumstance of the trains passing over nine switches at the foot of the inclined plane, must make the results appear a little greater than they would generally be on any other part of the road taken at random.

§ 6. *Friction of the intermediate Wagons of the Trains.*

We have already marked in the first six experiments the influence of the resistance of the air in the results. When five waggons move together, their resistance to the motion is 9.17 lbs. per ton; and if each of those five waggons move separately, their average resistance per ton is 11.65 lbs. The other experiments present similar results. By comparing large trains with those which are composed only of a small number of carriages, we constantly see the resistance diminish, when the mass which is drawn, although continuing to cut the air on the same surface, comprises, however, a more considerable weight.

The direct resistance of the air takes place only on the first carriage of the train. Now, the first six experiments made with a single wagon give us the resistance of a carriage when it advances the first. Deducting it therefore, in the other experiments, we shall discover the resistance of the intermediate wagons of the trains; that is to say, the friction, independently of the direct resistance of the air.

The experiments III., IV., V., VIII., and IX., put together, give us the average friction of a loaded wagon at the head of the train equal to 11.77 lbs. per ton. Taking, therefore, experiment VII., for instance, the weight of the train was 25.58 t. Each ton had a resistance of 9.17 lbs.; thus the total resistance was 234.5 lbs. Deducting the resistance of the first wagon at the rate of 5.12 t. × 11.77 lbs. = 60.25 lbs., there remain for the four following wagons 174.25 lbs., which, divided by the weight of those four wagons, make 8.50 lbs. friction per ton.

§ 7. *Table of the Results of the foregoing Experiments on the Friction of the intermediate Wagons of the Trains.*

If we make the same calculations for each of the other experiments, and if we add to them the similar results, already presented for the three experiments where the engines had remained attached to the trains, the following table will be made out:—

RESISTANCE OF THE INTERMEDIATE WAGONS OF THE TRAINS, THAT IS TO SAY, AFTER DEDUCTION OF THE DIRECT RESISTANCE OF THE AIR ON THE FIRST CARRIAGE.

Number of the experiment.	Description of the trains.	Weight of the trains.	Average weight per carriage.	Resistance per ton of the first carriage of the train.	Resistance per ton of the intermediate wagons of the train.
		tons.	tons.	lbs.	lbs.
II - -	5 wagons	25.58	5.12	11.77	8.50
I - -	5 wagons	31.31	6.26	11.77	7.92
XI - -	11 carriages	48.72	4.43	11.77	8.33
X - -	14 wagons	61.65	4.40	11.77	7.99
VII - -	19 wagons	92.00	4.84	11.77	7.91
XII - -	25 carriages	110.00	4.40	11.77	7.99
XV - -	8 carriages	33.52	4.00	15.84	9.04
XIII - -	18 carriages	86.76	4.78	13.78	7.21
XIV - -	21 carriages	101.80	4.83	15.22	7.35
	126 carriages	591.00	4.78	,,	8.03

The average resistance is therefore no more than 8 lbs. per ton, if we take into account only the intermediate wagons of a train. Now, in all the cases we have to calculate, in respect to railways, the train is always preceded by the engine. It is, therefore, upon that alone that the direct resistance of the air exerts its influence, and that resistance being already taken into account in what is called the friction or resistance of the engine, it is clear that all the wagons must be considered as intermediate carriages. Consequently, their proper resistance must only be reckoned at the rate

of 8 lbs. per ton. It is upon this proportion that we shall establish the resistance of the trains in all our experiments.

In the foregoing tables, the average weight of a wagon was 4.78 t. That wagon, placed at the head of the train, had a resistance of 11.77 lbs. per ton, or 56 lbs. for the whole; while, placed in an intermediate situation, its resistance was 8.03 lbs. per ton, or 38 lbs. in all. The difference between the results was owing to the obstacle of the air. The air created, therefore, a resistance of 17 lbs. to 18 lbs. on a wagon of a moderate height, as those were, and at the average speed of the experiments. That speed was of about 12 miles an hour, or 16 feet per second, a space of 10,000 feet having been, on an average, run over in 10 minutes.

This determination agrees with direct experiments made on the force of the wind. We know that when the wind has a velocity of 20 feet per second, it causes on a surface of a square foot a pressure of 0.915 lbs. or a little less than 1 lb. In other words, a surface of one square foot cutting the air with a velocity of 20 feet per second meets with a resistance of 0.915 lbs. Thus a loaded wagon presenting a surface of about 22.5 square feet must meet, from the atmosphere, with a resistance of about 20 lbs.

The direct resistance of the air against the first carriage of the train once deducted, the resistance per ton does no longer depend upon the number of wagons. The remaining differences seem to be the effect of accidental circumstances, such as the state of the rails, or the wind, or the greasing of the wheels, &c., which prevent those experiments from presenting a mathematical preciseness.

§ 8. *Experiments on the Friction of Wagons without Springs.*

The foregoing experiments having been made with wagons mounted on springs and constructed on an improved principle, one might perhaps suppose that common wagons, having no springs, would offer a greater resistance to the motion.

In order to clear up this point, some experiments were, at our request, undertaken on the Darlington Railway. They were conducted exactly on the same principle as the foregoing, by Mr. Robert B. Dockray.

The wagons employed were the common wagons in use on that line. Their wheels are 3 feet in diameter, like those of Liverpool. Their weight when empty, is 1.30 t., and 4 t. including the load. They are not mounted on springs, and the axle is 3 inches in diameter at the bearing.

We have seen that in the Liverpool wagons the axle in the same part is only $1\frac{3}{4}$ inches in diameter. This difference arises from the circumstance that in the Liverpool wagons, the support is *outside* the wheel, on a prolongation of the axle; and that part, the only service required of which, is to support the wagon, may be reduced to so small a diameter without depriving the middle part of the axletree itself of its usual strength. In the Darlington wagons, on the contrary, the bearing is *within* the wheel, like in common carriages. The support takes place, therefore, not on a prolongation of the axle, but on the axle itself; and this part cannot be less than three inches in diameter, because it must not only bear the weight of the wagon, but also maintain the wheels in a fixed situation, by resisting the lateral pressure and the twisting forces which are continually exerted against the wheels during the motion.

With those wagons the experiments on friction gave the following results:—

EXPERIMETS ON THE FRICTION OF WAGONS WITHOUT SPRINGS.

Number of the exp'riment	Number of wagons in the trains	Distance run over by the wagons before they stopped.	Difference of level between the starting and arriving points.	Friction.	Friction per ton in lbs.
		ft.	ft.		lbs.
I	12	9,552	35.64	$\frac{1}{276}$	8.11
II	4	9,600	34.60	$\frac{1}{277}$	8.07
III	16	10,500	35.04	$\frac{1}{300}$	7.48
IV	8	9,894	34.82	$\frac{1}{284}$	7.88
				Mean	7.88

During those experiments, the wind blew with a moderate strength in favour of the motion, which is a point to be considered; for we know that trains of wagons are sometimes propelled to a considerable distance on railways, by the force of the wind alone. All the wagons were in good order, and particularly those of experiments III. and IV., which were, besides, the best on the line.

These experiments having, contrary to the naturnl expectation, given more advantageous results than those which had been obtained with wagons mounted on springs, it became neccssary to determine exactly the influence of springs on the resistance to motion.

In consequence, the platform of a wagon mounted on springs, having been wedged so as to raise it *off* the springs, the wagon was loaded with pigs of lead, weighing 2 tons, and in that state it was left to its gravity on the inclined plane. The resulting friction was 8.58 lbs. per ton.

Then the wedges were struck out, so as to let the platform descend on the springs again, and the experiments having been repeated, gave a friction, per ton, of 8.35 lbs.

There exists, consequently, a small advantage in making use of springs; but that advantage is easily compensated by some adventitious circumstances, as better polished bearings, better greasing, a load giving less hold to the air, &c.; and, in one case as well as in the other, the *average* friction must be reckoned at 8 lbs. per ton.

CHAPTER IV.

ON THE FRICTION OR RESISTANCE OF THE ENGINES.

ARTICLE I.

ON THE FRICTION OF ENGINES WITHOUT LOAD.

§ 1. *Of the different modes of Determination.*

After having determined the resistance opposed by the loads that are to be moved, it was also necessary to ascertain the resistance belonging to the moters themselves, for it is only the surplus of their force, beyond the power they require to move themselves, which those moters can apply to the traction of loads.

The friction of a locomotive engine is the resistance which that enginc opposes to motion. It is the force that must be applied to it, to overcome all the frictions that oppose its progress, at the moment it executes the traction of a train. At that moment it must evidently possess: 1st, a certain power sufficient to make the train advance or to overcome the resistance of all the loaded carriages; 2nd, another power sufficient to repel the engine itself along and overcome its own friction. It is this second power, the power that propels the engine, which is the friction of that engine, or, rather, which is equal to the *friction of that engine;* whilst the first is *the resistance of the load;* and whilst both the powers together constitute *the total power applied by the moter.*

The power required to move a locomotive engine differs according to three different circumstances.

1st. If the steam remains shut up in the boiler without having any access to, or exercising any pressure on, the mechanism, so that the progress of the engine be produced by an external agent, the engine, moreover, drawing no load.

2nd. If the steam is the agent that produces the motion; but if, as in the first case, there is no train attached to the engine.

3d. If the engine cannot move without drawing after it a load, the resistance of which, creating an increase of pressure on all the parts of the mechanism, must necessarily augment the friction on every one of its joints, and consequently, the total resistance of the engine.

The difference between the first and second case cannot be very great; for, in both circumstances, the load of the engine remains the same, being nothing more than its own weight. Besides, by whatever means it is made to move, it advances; so that at every turn of the wheel, there is a complete revolution, and, consequently, a complete friction of the whole mechanism. The steam would have applied a certain force to make the engine move. That force would have produced pressures, and, consequently, proportional frictions on all the compressed points, as upon the crank of the axletree and all the joints in general.

Now, as soon as we make the engine advance, we apply a force equal to that which the steam would have applied. Consequently, we produce on the crank and on all the joints the same friction that would have been produced by the force owing to the steam. Of all these joints, those only upon which the steam acts in a direct and particular manner, cease to be compressed equally in the two cases. These parts being strongly pressed against one another, when the steam is admitted into the cylinders, cease to experience that pressure, and have, in consequence, evidently less friction when the steam takes no part in the creation of the motion. But the only parts on which the steam exercises a direct pressure are the two slides.

The surface of the slide, on which the pressure of the steam takes place, is, in general, 7½ inches long to 6 inches broad, or 45 square inches, which makes 90 square inches for the two slides together. When we talk of the engine moving alone, and without drawing any load after it, we cannot suppose that the pressure of the steam in the boiler need to surpass 10 lbs. We shall find, by experiment, that it may happen not to be above 4 or 5 lbs. The pressure exercised by the steam on the slides, amounts, therefore, at most, to 900 lbs. So that, taking the friction of iron on iron, ground and polished, at $\frac{1}{10}$ of the pressure,* we shall have a friction of 90 lbs. But we know that the real resistances on different points of an engine are in the ratio of the velocity with which those parts move. The slide only moves three inches for each stroke of the piston, or half a foot for each turn of the wheels; that is to say, that it only runs over a space of half a foot, while the engine having a wheel of five feet, advances 15.71 ft. The friction of the slide, considered as opposing itself to the motion of the engine, creates, therefore, a final resistance only $\frac{90}{2 \times 15.71}$ lbs. or about 3 lbs. From which we see, that, in practice, the friction occasioned either in the first case or in the second, may be considered as being the true friction of the engine, when it draws no load.

As for the difference between these two first cases and the third, we know that the friction is always in a direct ratio to the pressure. Now, it is evident that the pressures which take place on the rubbing parts of the engine, vary in proportion to the load it draws. That principle is true, provided the weight of the engine itself is taken as a part of the load. The only parts which are excepted from that rule are: the piston, which remains in all cases pressed in the same manner, the steam having no access into its interior; the slide, the friction of which varies with the pressure in the boiler, which depends only indirectly upon the load; and, lastly, the excentrics, the friction of which follows the friction of the slides. All the other parts of the engine are subject to the rule laid down above. The principal pressure takes place on the crank of the axle, and that pressure is exactly in proportion to the load.

There must consequently be a considerable difference in the friction of an engine when loaded or when without a load. We shall have recourse to experiments to determine that difference.

First, we shall endeavour to make ourselves acquainted with the friction of the engine without a load, and then we shall come back to the second part of the problem which consists in determining the influence of the load upon that friction. By that means we shall be able to calculate the resistance of locomotive engines in all circumstances.

§ 2. *Friction of the Engines determined by the least Pressure.*

The considerations above stated, which tend to prove that the power necessary to move an engine is very nearly the same, whether the force of the steam itself, or any other external agent, is employed, furnished us with two means of ascertaining the friction of engines without a load. The first consisted in seeking what was the least pressure of steam required by a locomotive engine to put itself in motion on the rails, when it had no other resistance than its own to overcome; the second was the method already employed in regard to the wagons. Both were successively tried.

The principle upon which the first of these two methods is founded is the following:—

If we find that the steam, by causing a

* According to the experiments of Coulomb on the resistance of surfaces.

known effective pressure per square inch, can make the engine advance, the area of the two pistons in square inches being known, it is easy to calculate the total force applied by the steam on those two pistons. That force being sufficient to make the engine advance,—that is to say, to conquer its resistance,—it gives of course the value of that resistance. It must only be observed according to the principle known in mechanics by the name of *the principle of virtual velocities*, that the pressure exercised on a part of an engine, being transmitted to another part of the same engine retains the same intensity only in case the two parts have the same velocity. If not, the force or pressure is reduced in an inverse ratio to the velocity of the points of application. This principle appears in an evident manner and *a priori*, in simple machines like the lever, the roll, the pully, &c. Inspection alone is sufficient to demonstrate, that if a force can, by the aid of the machine, raise a weight four times as great as itself, it is only by travelling, in the same space of time, four times as far as the weight it raises. In the case before us, the velocity of the piston is to that of the engine as twice the stroke is to the circumference of the wheel, the piston giving two strokes while the wheel turns once round. A force applied on the piston produces, therefore, in regard to the progress of the engine an effect reduced in the same proportion, that is to say, as twice the stroke is to the circumference of the wheel.

Let d be the diameter of the piston, and π the ratio of the circumference to the diameter, $\frac{1}{4}\pi d^2$ will be the area of one of the two pistons; and p being the *effective* pressure of the steam per square inch,

$$\tfrac{1}{2}\pi d^2 p$$

will be the *effective* pressure upon the two pistons. If, moreover, l express the length of the stroke, and D the diameter of the wheel, the effective force of transfer resulting for the engine, in consequence of that pressure, will be

$$\tfrac{1}{2}\pi d^2 p \times \frac{2l}{\pi D}, \text{ or } \frac{pld^2}{D},$$

which, according to what we have said, gives the measure of the resistance of the engine.

Here it must be noticed that we suppose the pressure of the steam in the cylinder to be equal to that in the boiler. The reason is, that in the experiments we shall have occasion to make, the motion of the engines being always extremely slow and the regulator completely open, the two pressures have time to put themselves in equilibrium, and are consequently equal. It must also be observed that the *effective* pressure p of the steam, or the surplus of the total pressure over that of the atmosphere, is not the true moving power residing in the steam. That moving power is the *total* pressure of the steam, which we shall express by P. But, on the other hand, the true resistance on the piston is neither that only which results from the traction of the engine. It comrpises also the atmospheric pressure, which takes place either directly or intermediately on the other face of the piston, as well as upon every other body in communication with the atmosphere. So, we omit on both sides an equal quantity, viz. the atmospheric pressure. Nothing prevents us here from simplifying in that manner; because having to compare the power and the resistance only in a case of equality, that equality is not destroyed by substracting an equal number on each side.

To succeed in ascertaining the least pressure by which the engine could be moved, it was necessary to take the engine at the instant when it furnished the steam at a very low degree of elasticity. In the evening, after the work was finished and the fire taken out of the fire-box, the water of the boiler began to lose its heat, and the steam that it generated also gradually lost its force. This was the proper moment to ascertain the least pressure by means of which the engines were able to advance on the rails. The spring-balance that shut the safety-valve enabled us to ascertain the pressure of the steam in the boiler, by loosening the spring until it stood in exact equilibrium with the pressure. It was then easy to calculate the pressure from the degree marked on the balance. However, to make all calculation unnecessary, the engine was brought to the mercurial gauge, which gave immediately the pressure per square inch in the boiler, at the moment of the experiment. It is in that manner that the following experiments were made:—

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I. On the 5th of July, the ATLAS engine, cylinders 12 inches diameter, stroke 16 inches, weight 11.40 t., wheels five feet, four wheels coupled, was submitted to the experiment separated from its tender.

The spring of the balance having been successively loosened, to show the pressure of the steam in the boiler in proportion as it went down, the following trials were made :—

At 2 lbs. pressure, marked by the balance, the engine moved backwards and forwards, passing from a state of rest to one of motion, or conquering, besides the friction, what is called the *vis inertiæ* of the mass of the engine ; that is to say, not only maintaining an acquired velocity, but acquiring one which proves a surplus of force in the moving power.

At 1 lb. pressure, marked in the same way, the engine started, passing from a state of rest to one of motion.

The pressure diminishing a little more, the engine *continued* moving. At that moment we brought it under the mercurial gauge. It marked 4 lbs. effective pressure per square inch in the boiler, the valve then bearing no more than the weight of the lever, or a little less, which could not be ascertained, the balance not going below zero.

The cylinder being 12 inches in diameter, the area of the two pistons was 226 square inches. Thus a pressure of 4 lbs. per inch produced on the pistons a force of $226 \times 4 = 904$ lbs. that is to say, was able to move the resistance of 904 lbs. at the velocity of the piston. But at the velocity of the engine, which is greater in the proportion of the circumference of the wheel to twice the stroke, or $\frac{15.71}{2 \times 1.33} = 5.887$, that same force was only able to overcome a resistance of $\frac{904}{5.887} = 154$ lbs.

Thus, as we have seen that the engine continued moving at the moment it was brought under the steam gauge, though the pressure was then reduced to 4 lbs., we see that the resistance of the engine did not exceed 154 lbs.

This first experiment was made with the engine separate from its tender, with a view not to counteract one resistance by the other ; but, in wishing to apply it to lighter engines, of which the wheels were not coupled, a difficulty occurred. The pressure required for the engine to move without tender was so very low that the spring-balance could not mark it, that pressure being less than the weight of the lever itself. Another inconvenience of that low pressure was, that it could only be obtained at the moment the boiler generated no more steam at all ; the consequence of which was that at that moment the pressure diminished so rapidly that no confidence could be put in the accurracy of the experiment.

But as the resistance of the tender could be easily calculated by the experiments made on the friction of the carriages, and already inserted above, it was also easy to take it into account. Thus, by having the tender attached to the engine, the experiment presented the same degree of accurateness, with more facility in observing the pressure of the steam. It is for that reason that, in the following experiments, the tender was no longer separated from the engine :—

II. On July 21, the SUN engine, cylinders 11 inches, stroke 16 inches, weight 7.91 tons, wheels 5 feet ; only one pair of wheels worked by the piston, was submitted to the same experiment.

At 6 lbs. pressure by the balance, the engine started, followed by its tender full of coke and water.

At 4 lbs. the same.

At 2 lbs. the same.

At 1 lb. pressure the engine started also.

With the weight of the lever alone, the balance marking no pressure at all, the engine started again.

The pressure still a little further diminished, the engine did not start, but, once put in motion, continued going.

At that instant we brought it under the mercurial gauge ; it marked 5½ lbs. pressure per square inch, so that at that pressure the engine can move, followed by its tender.

The area of the two pistons (11 inches in diameter) being 190 square inches, a pressure of 5.5 lbs. per inch, produced on the piston a force of 190×5.5 lbs. = 1,045 lbs. at the velocity of the piston, and thus a draft of $\frac{1,045}{5.887} = 177.5$ lbs. at the velocity